Meeting UK Needs in the Biosciences

AGRICULTURAL AND FOOD RESEARCH COUNCIL ANNUAL REPORT 1992 - 1993

To The Chancellor of the Duchy of Lancaster

The Agricultural and Food Research Council, as required by Schedule 1 of the Science and Technology Act, 1965, submits the following Report on its activities during the period from 1 April 1992 to 31 March 1993.

Sir Alistair Grant,
Chairman
Professor T L Blundell FRS,
Deputy Chairman and
Director General

Laid before Parliament pursuant to Schedule 1 of the Science and Technology Act, 1965.
24 November 1993.

About this Report:

It is the Council's practice to compile the Annual Report around a theme, rather than to provide an exhaustive review of all of the research programmes. Recent examples have been:
Protecting the Quality of Life (1988/89)
At Work Around the World (1989/90)
Investing for the Future (1990/91)
and *A Basis for Sustainability* (1991/92).

This year's Report takes as its theme *Meeting UK Needs in the Biosciences*. The cover shows computer generated images of:

- a plant virus manipulated to carry a fragment of foot-and-mouth disease virus - a potentially exciting approach to vaccine technology for the pharmaceutical industry *(page 15)*.
- geographical distribution of crops under different climate scenarios - a tool for designing policies for land use to meet the challenges and opportunities of environmental change *(page 32)*.
- predicted gene flow between grassland communities - part of a programme on control methods and risk evaluation, crucial to public debate about the acceptability of biotechnology *(page 54)*.

Where appropriate the names of research leaders are given in this Report. However, general enquiries about the contents of the Report should be addressed to:

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The mission of the Agricultural and Food Research Council is to advance scientific knowledge for agriculture, food and other biology-based industries and for sustainable use of land and biological resources.

From April 1994 AFRC will be incorporated into the Biotechnology and Biological Sciences Research Council (BBSRC).

The Council is funded primarily from the Science Budget of the Office of Science and Technology (OST). For some of the research conducted in institutes, it also receives commissions from the Ministry of Agriculture, Fisheries and Food (MAFF), examples appear on pages *11, 25, 31, 34, 35, 38, 39, 44* and *51*. In addition the Council receives funding from other Government Departments, the EC, and from commercial companies. This Report includes highlights of research funded by all of these means. Results of the research add to the scientific knowledge base, have relevance to policy needs of several Government Departments and in many cases are being rapidly exploited by industry.

The Council provides the Scottish Office with strategic advice and scientific assessment on the work of the independent research institutes in Scotland (SARIs).

Scottish Office funded research at the SARIs includes work of special relevance to the agriculture of northern Britain as well as contributing to the overall UK science effort. An example is given on page *35*. Work at the Scottish institutes is also supported by industry, the EC and others.

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MEMBERSHIP OF COUNCIL

AT 31 MARCH 1993

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Deputy Chairman & Director General

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Chief Scientific Adviser, MAFF

Mr C R Cann
Deputy Secretary, Countryside, Marine Environment and Fisheries, MAFF

Professor E C D Cocking FRS
University of Nottingham

Professor J R Coggins
University of Glasgow

Professor J M M Cunningham CBE
Formerly West of Scotland College of Agriculture

Sir Sam Edwards FRS
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Mr D F R George OBE
Dyfed Seeds

Mr A B N Gill
Deputy President, NFU

Professor R M Hicks OBE
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University of Cambridge

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Farmer

Mr G T Pryce
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Chief Scientist, Agriculture & Horticulture, MAFF

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Dr D A Rees FRS - **MRC**
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AFRC SENIOR STAFF

Professor T L Blundell FRS
Deputy Chairman & Director General

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Director of Administration

Professor R B Heap FRS
Acting Director of Science

Dr A V Harrison
Head of Policy Division

Mr R J Price
Head of Human Resources

Mr S H Visscher
Chief Finance Officer

Dr J N Wingfield
Head of Science Division

▲ Terry Pryce (centre) in discussion with the Chairman and Peter Richmond (left) General Manager, Technical Group, Cooperative Wholesale Society, at a Council reception for senior figures in the UK agric-food industries.

Terry Mansfield FRS (right) Chairman of a Visiting Group to the John Innes Centre, in discussion with some Group members. ▼

▲ Council meeting at the Royal Society, June 1993.

▲ Chris Leaver FRS discussing a Royal Show exhibit on an EC programme on molecular screening of biodiversity with the coordinator Angela Karp.

The Director General with John Krebs FRS (right) presented evidence to the House of Lords Select Committee on Science & Technology, May 1993. ▼

Chairman's Statement

Although this Report covers the year to 31 March 1993, its publication after the Government's White Paper (*) means that it would be inappropriate not to review the year with at least one eye on the exciting opportunities that lie ahead. For this reason we are showing how the Council's programme of research is already well positioned to meet the opportunities and challenges raised by Government. Indeed, we introduce each of the three scientific sections of this Report with a brief extract from the White Paper.

During the year, the Council has reviewed and redefined the output of its research in terms of benefits for its diverse user groups, customers and the wider range of institutions or bodies affected by the Council's activities. Principal objectives have been to improve mutual understanding and to develop improved mechanisms for information exchange and technology transfer. This process is continuing. It parallels much of the thinking evident in the White Paper, and aspects of our philosophy are reflected in the format of this Report. We illustrate how the Council's research underpins innovation and new technologies to increase the competitiveness of a wide range of industries; how it supports national policy making and effective UK participation in European and wider international initiatives; and how it addresses public concerns about the impact of biotechnology and biology-based industries on the quality of life.

Most scientists do not require a second invitation to describe their research and to explain its significance. I am delighted, but not surprised, therefore, by the enthusiastic way in which the Council's staff have responded to our initiatives and to the Government's re-organisation of the Research Councils to conduct basic, strategic and applied research within specific missions that recognise the needs of user communities. There is no contradiction in our twin objectives of providing world-class fundamental science and at the same time ensuring that our research contributes as fully as possible to national wealth creation and well-being.

I am encouraged that the excitement of fundamental research and a commitment to find solutions to real problems are evident at all levels in the Council. The year 1992–93 has been a productive and successful one for the Council and we look forward to building upon our achievements in the new Biotechnology and Biological Sciences Research Council to be established next year.

Sir Alistair Grant
Chairman
November 1993

(*) The Government's White Paper "Realising our Potential: A Strategy for Science, Engineering and Technology" (Cm 2250, HMSO) was presented to Parliament by the Chancellor of the Duchy of Lancaster on 26 May 1993.

Director General's Report

AFRC and The White Paper

Last year's establishment of the Office of Science and Technology (OST) and announcement of the White Paper guaranteed intense discussion during the year about scientific structures and technology interactions. Mr Waldegrave's invitation to academia and industry to participate in the debate was particularly welcome; we were pleased to be able to contribute on the basis of our experience as a research council with a clear mission, a mixed economy of research structures and a long history of successful technology interactions with industry.

The AFRC was established as a mission-oriented Council and has always related research in its institutes and university teams to strategic objectives in support of agriculture, food and other biology-based industries. Chemists, biologists, engineers and agriculturalists involved in AFRC research have worked closely with these industries, but they have also been quick to recognise emerging technologies - genetic engineering, information technology, mathematical modelling - that would provide the science drive for innovation. For much of AFRC's history it has balanced market pull with scientific opportunity in an effective way. It has contributed towards the efficiency of the agricultural and food industries through new crops and livestock, improved mechanisation, the control of plant and animal disease and the improvement of food quality and safety.

There have been many views on how best to exploit basic science in the UK. Unlike those who have argued for the concentration of strategic applied research in a single research council, our evidence to Mr Waldegrave emphasised the importance of continuous interactions between the science base and those in industry and policy departments. We argued that this would allow the beneficiaries of scientific research to stimulate and contribute to the prioritisation of the research programmes in the science base. This is particularly important in the chemical, agricultural, pharmaceutical, environment and other biology-based industries where application of new discoveries is rapid. We proposed six mission-orientated research councils; one of these focused on the needs of these biotechnological industries. We are delighted that this structure has been adopted by Government.

The bio-revolution emerged partly from the application of physics and chemistry to biological problems and partly from the understanding of the genetics of micro-organisms, plants and animals. Its effective exploitation requires advanced engineering - bio-chemical, process and mechanical - together with modern information technology. We are delighted that this is now clearly recognised in the remit of the new Biotechnology and Biological Sciences Research Council (BBSRC) that will be established in April 1994. The BBSRC will both reflect multidisciplinarity in the funding of its research, and the broad range of user-communities from applications in food, pharmaceuticals, fibres, specialist chemicals, fuels and construction materials.

New opportunities for biology-based industry

This Annual Report emphasises the new technologies which will underpin biology-based industries of the future. We show that the new biology can lead to valuable industrial crops. On page 13 we describe how oilseeds can be modified to optimise oils for the manufacture of nylon polymers, plastic coatings, lubricants, cosmetics and pharmaceuticals. We also describe how plants can be adapted to express fragments of animal viruses offering a potentially safe and inexpensive means of vaccine production (page 15). We

▲ **Dr Denis Murphy, who leads the team working on genetic manipulation of oilseeds at the John Innes Centre, discusses his OST-funded work with the Minister of Agriculture, The Rt Hon Gillian Shephard.**

explain how the behaviour of biological molecules at interfaces may be exploited in the production of synthetic stabilisers and emulsifiers for the food and pharmaceutical industries (page 21) and we describe the field experiments being used to identify potential fuel crops that are most suited to UK conditions (page 22). A proper understanding of the nature of the chemical bonds between fibrous and non-fibrous materials and how they are broken should provide a basis for improving fibre crops, and developing new applications; examples include the use of linseed fibres for chipboards with high tensile strength, blankets to control soil erosion and panelling for vehicles (page 23).

We also describe novel strategies to combat plant virus replication; new insights into mechanisms by which a virus replicates in plant cells should allow us to identify targets for blocking replication and making plants resistant to viral attack (page 12). We describe genome mapping in cattle which will help us identify traits for breeding (page 10). A better understanding of the mechanisms of flavour development should help plant breeders and food processors to improve product quality and match it to market demand (page 14). These developments will improve the efficiency and competitiveness of our industry, decreasing costs and improving profits; they will also contribute to the quality of life by decreasing the environmental impact of intensive agriculture.

There is exciting research on recombinant enzymes for the food, animal feed and paper industries. On page 18 we describe how recombinant DNA technology can be used to study the structure and function of enzymes which can hydrolyse plant cell walls. Their catalytic activity can be enhanced and they can be re-designed to match the requirements of industry. Such novel developments are also assisted by a proper understanding of the three dimensional structure of the enzymes. In a very exciting development from the Institute of Food Research (reported on page 19) the three-dimensional structure of the enzyme pectate lyase is described. This is a fascinating discovery in terms of a totally unexpected and novel protein architecture - parallel β-sandwich. This information could be used to help modify peptides for applications as a gelling agent and for improving the process of fruit juice clarification.

Technology interaction and transfer

Technology interaction encompasses a wide range of activities to further the exchange of ideas, knowledge and technology between AFRC institutes and industry. Technology transfer is an important component. We have established a Council Committee on Collaboration with Industry, under the Chairmanship of Dr Tom Little, to evaluate our activities in this area and to recommend future policy.

Specifically, we are very pleased that a new research and marketing agreement has been established with Agricultural Genetics Company (AGC). This confirms that AGC will act as the principal channel for the commercial exploitation of discoveries in plant and microbial science (by IACR and IPSR). The new agreement will operate on a non-exclusive basis and will run until July 1998. Institutes have many individual collaborations with industries, for example the Roslin Institute with the high-tech company Pharmaceutical Proteins and Rothamsted Experimental Station of IACR with Zeneca at Jealott's Hill. We have had regular meetings with the National Farmers Union organised through their Vice President and AFRC Council member, Ben Gill; these have been very helpful in identifying the needs of the agricultural industry for new science and technology.

We are delighted that our close interactions with the Royal Agricultural Society of England will be further strengthened in the coming year. I would like to congratulate our Chairman, Sir Alistair Grant, on his appointment as President of the RASE for 1993/94. This will underline the importance of close working between the pre-farm gate agricultural industry and the post-farm gate food industry; our research must also reflect this vertical integration. Reports of the Priorities Board for Research and Development in Agriculture and Food, which has been broadened to include the whole food chain, provide an important mechanism to orient our research to meet perceived needs in these industries.

We can also measure our success in technology transfer. For example, Pharmaceutical Proteins have successfully negotiated with Bayer for the exploitation of their sheep transgenic technology which allows high value pharmaceuticals such as Factor IX to be produced in sheep milk. The Queen's Award for Technological Achievement 1992 was awarded to Silsoe Research Institute (jointly

▲ **Mr Wang Zing Zengrong, Science Counsellor at the Chinese Embassy in London, presents Dr Mike Adams of Rothamsted with the First Class Award of the Ministry of Agriculture of the People's Republic of China.**

with Shelbourne Reynolds Engineering Ltd) for their work on the stripper header, a very effective way of harvesting grain, cotton and many other crops. Silsoe Research Institute also won the Archimedes Award for Excellence in Engineering for the patch sprayer - "a product most likely to preserve or improve the environment".

Polices for international cooperation and technology transfer

Knowledge of one plant or animal can now be applied more easily than hitherto to quite distant relatives. For example, genes for pest resistance, once engineered into one crop can often be transferred quickly to other species. The new biology can cross the boundaries of the traditional commodity industries; we can transfer technology from the temperate west to the tropical south. Thus, there are increased opportunities for collaboration internationally and for transfer of our new technologies to developing countries.

This has been exemplified in a very interesting OECD report on biotechnology, agriculture and food, to which research directors, Professors Doug Georgala, Brian Heap FRS and Dick Flavell have contributed thoughtful chapters. The Scientific Editor was Sir Barry Cross FRS, former director of IAPGR, who with the AFRC organised a successful public launch in the UK. This was attended by many Government policy makers and UK industrialists. There has also been increasing interest in research for the developing countries. On page 46 of this Report we describe two new initiatives. Rothamsted International is designed to increase interactions between Rothamsted scientists and those in developing countries, through research fellowships and collaborations. AFRC is supporting the International Service for the Acquisition of Agri-biotech Applications (ISAAA) to facilitate cooperation between biotechnology industries, AFRC institutes and developing country research institutions in order to assist the sharing and transfer of technology. Developing countries that have a strong science base, for example, Mexico, Zimbabwe and China, are showing an intense interest in the new plant biotechnologies. On a recent visit to China I saw many experiments where genes for viral resistance had been transferred into crops including tobacco, rice and wheat; transformed crops have shown resistance even after six generations. AFRC has good collaborations with China. Indeed, Dr Mike Adams of Rothamsted has recently received an award for first class research involving Chinese and UK scientists; the research was selected by the Chinese State Committee for Science and Technology as one of the top ten science projects for 1992.

To highlight existing links and new opportunities we have produced a booklet describing research in the AFRC which is relevant to developing countries. It reviews our collaboration with Zimbabwe to improve agricultural equipment, with Peru on potato growing and with Indonesia on statistical analysis of experiments. In future I believe that basic and strategic research funded by OST will have an increasing role in underpinning the work of the Overseas Development Administration (ODA).

AFRC structures and organisation

The AFRC has supported a mixed economy of research structures in which grant-aided institutes compete with university units and project teams for funding of research programmes. The institutes can contribute multi-disciplinary research teams that are focused on objectives and do not have to reflect teaching requirements. The institutes can also offer specialist facilities and continuity in research programmes. The university groups on the other hand can very quickly cross traditional boundaries to take advantage of new opportunities. Both competitive and collaborative aspects are emphasised in our coordinated research programmes that bring together institutes and universities (page 61).

In this mixed economy of structures we must continue to review and monitor our research institutes. The research stations of the former Institute of Animal Physiology and Genetics Research at Babraham and at Roslin had each developed outstanding basic, strategic and applied research programmes. We therefore decided to establish them as independent institutes. A review of the Nitrogen Fixation Laboratory (NFL) presently at Sussex University, showed that their expertise in metallo-enzymes, biochemistry and microbial genetics needs to be more closely integrated with other plant and microbial science; it has important contributions to make outside the area of nitrogen fixation. For this reason we have decided to move the NFL to the John Innes Centre in Norwich.

Many of our institutes have long and distinguished histories. We have been pleased to participate in the celebrations of Rothamsted Experimental Station on their 150th anniversary in 1993, and we are delighted that Her Majesty The Queen has graciously agreed to be Patron of Rothamsted including Rothamsted International. The Station has made major contributions to both national and international agricultural research and is strongly positioned, with excellent new science and technology, to make contributions long into the future!

In AFRC we continue to debate structures for our research committees. Within BBSRC this will again become a major topic for discussion. Should they reflect the nature of the biological organism studied: microorganisms, plants and animals? Or should the research committees mirror the level of organisation in the biological system: molecule, cell, organism, population, system? And how can council structures best reflect the interests of industry and the wider user communities.

One concern over the past year has been our funding of engineering. We felt that we had insufficient expertise to judge engineering research programmes within the animals, plants and food research committees. We have, therefore, established a new engineering research board to consider research policy as well as to monitor the research in institutes and to assess university research grant applications. The board is chaired by Professor Roland Clift.

We have recognised a need for better information about research programmes, so that we can supply information more rapidly to OST, MAFF and other Government Departments as well as improve our own planning process. For this reason we have launched a new information data base, OASIS, which is accessible throughout the Council.

Biotechnology and the public

The increasing role of genetic engineering in the application of biology has heightened our awareness of the importance of public perceptions and acceptability. As Professor John Durant has recently written in his interesting introduction to "biotechnology in public":

> *"…. all major technological revolutions have enormous and partly unforeseeable ecological, economic, ethical, legal, social and political repercussions".*

The new biotechnology, especially that which involves genetic manipulation, will be no exception. There are already worries about whether it is natural, ethical, safe, socially desirable and economically advantageous. There are fears of its potential and of the dangers of "playing God". John Fincham and Gerry Rivetz have suggested that scientists must show:

> *"A certain attitude of scientific humility, an awareness of partial ignorance, and of the human fallibility of those operating the safety system".*

We must listen to public worries and, even if they seem irrational or unreasonable, treat them seriously. For this reason we have made a study in the Think-Tank of the public perception of risk. With the help of John Durant we are also initiating consensus conferences, which will involve lay members of the public in discussions of new technologies.

We have a responsibility to communicate the new science in a way that is understandable to the public. To meet this objective we have strengthened our links with schools and schools' organisations; several publications have been produced jointly with the National Centre for Biotechnology Education (pages 52-53). We have also had extensive discussions with the public, with farmers' groups and with pressure groups on new biotechnologies.

Ultimately it must be the public that makes decisions about biotechnology on the basis of its social, legal, economic and other repercussions for the future. We must make sure that the public can participate knowledgeably in the debate. However, although we must all be aware of the fragility of our knowledge and conscious of our ignorance, I believe that we can justifiably be optimistic about the contributions of the new biotechnology.

Technology foresight

It is equally important to make sure that we have identified the most important emerging technologies. AFRC has been proactive in this area; for the past two years we have operated an active foresight programme in the form of the Think-Tank. This has considered new technologies that might impact on our research and has also endeavoured to assess priorities on the basis of market pull. For example, we have made extensive surveys of the new opportunities arising from plant biotechnology, especially non-food and industrial applications of agriculture and other biotechnologies. We have also organised a series of workshops about "meat versus wheat". How efficient are crops and livestock in producing food? How does it depend on the geographical area or the structure of the rural community? How sustainable are the systems? How do meat and wheat contribute to our diet and what is the minimum requirement for meat and wheat in the supply of micronutrients? Such questions are at the centre of market pull in the foresight exercise. Our papers on these topics should form a major contribution to the foresight exercises that the OST are now initiating and which will be most important to the setting of priorities in the new research councils.

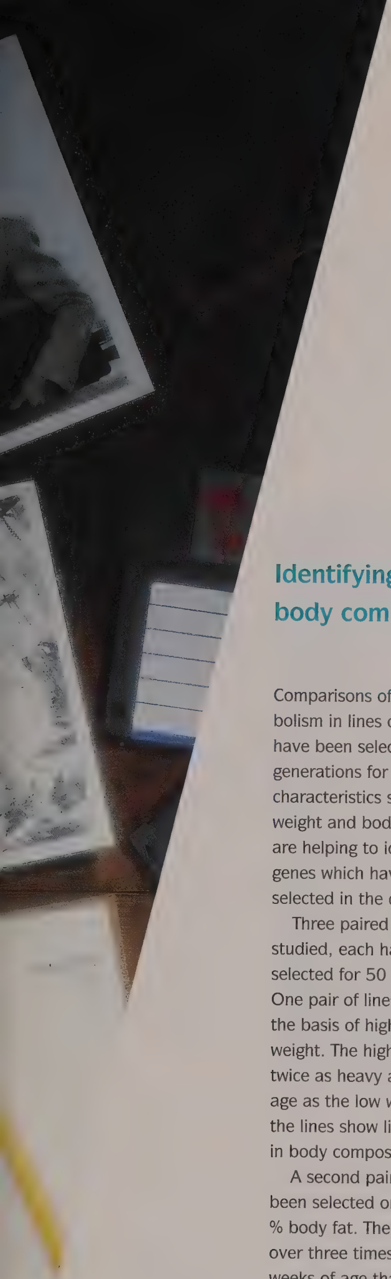
Tom Blundell FRS
Director General

New opportunities and technologies for biology-based industry

> ***"The understanding and application of science are fundamental to the fortunes of modern nations... (1.1)***
>
> ***"Advanced technology features increasingly in the processes used throughout manufacturing and service industries. High-technology products represent a growing share of the country's manufacturing output. Innovation is essential across the whole range of goods and services. It can be achieved through an incremental improvement or it can be a new approach to a well known process or product. In either case, knowledge of the possibilities of science and technology is a powerful ingredient in innovation." (2.4)***
>
> *Realising our Potential: A Strategy for Science, Engineering and Technology.*

The Council's research covers work from the molecular level to full agricultural and environmental systems. This has created several powerful generic technologies, for example, genome mapping, recombinant DNA technology, protein engineering and information technology. These are applicable to a wide range of plant, animal and microbial systems used in biology-based industries. They offer new opportunities for increasing productivity; for the development of safer and cleaner technologies; for new industrial feedstocks; and for the development of products and processes.

Close collaboration with industrial partners and through consortia and joint Government/industry schemes characterise many areas of the Council's research.



Genetic analysis

Identifying the genes that determine body composition and growth

Many commercially important traits of livestock such as growth rate and body composition are determined by the action of several genes working in concert. These genes are known as quantitative trait loci (QTL). Commercial animal breeding would be greatly advanced by better understanding of which genes are involved and how they exert their influence, for example, through altering energy metabolism and partitioning in animals.

Comparisons of body metabolism in lines of mice that have been selected over many generations for different characteristics such as body weight and body composition, are helping to identify the genes which have been selected in the different lines.

Three paired lines are being studied, each having been selected for 50 generations. One pair of lines is selected on the basis of high or low body weight. The high group is over twice as heavy at 10 weeks of age as the low weight line, but the lines show little difference in body composition.

A second pair of lines has been selected on the basis of % body fat. The high fat line is over three times fatter at 14 weeks of age than the low fat line, but the lines show little difference in lean tissue mass. The third pair of lines has been selected for differences in food intake.

The metabolic characteristics of the different lines are being analysed and compared. For example, it has been shown that selection responses in body size are not due to genetic changes in production of or sensitivity to growth hormone.

This research will also aid the design of animal breeding programmes, for example, by identifying how long selection response persists and how it is influenced by artificial and natural selection. There is evidence that, for example, the relationship between body size and litter size in mice is positive but then reaches a plateau before becoming negative.

New variation is produced in populations by mutation and in long continued selection programmes spontaneous mutations are likely to be important contributors to response. Estimates of the extent of spontaneous mutation in maintaining variation and studies on how mutant genes become fixed in a population should suggest strategies by which breeders might make optimal use of mutations that occur.

William Hill,
University of Edinburgh

Genome mapping in cattle

The rate of genetic gain in cattle breeding could be increased if breeders could select bulls using markers indicative of particular performance traits, rather than having to wait for results of progeny testing.

Identification of appropriate genetic markers for such "marker assisted selection" is one objective of a global collaboration to map the bovine genome. The EC contributes to the European part of this project "BovMaP" which involves more than thirty EC and EFTA laboratories.

Economically important traits, such as growth rate, are controlled through the concerted action of several genes, dispersed across the genome. To identify regions of the genome that are involved and to find markers for their selection requires maps of the physical location of markers and the pattern of their inheritance. More than 300 markers have already been assigned to chromosomes or linkage groups. These markers offer increased precision in animal identification and parentage control. In the long term the genomic map will include markers associated with a wide range of performance traits and heritable defects. In addition the map will enable breeders to understand and maintain the genetic base of selected populations. For example, the map will help to optimise quantitative traits such as growth or milk production and avoid the simultaneous selection of genetic defects such as Bovine Leucocyte Adhesion Deficiency (BLAD). Breeders will be able to take advantage of the information from this work on genome analysis through the Cattle Blood Typing Service at Roslin.

Ross Miller,
Babraham Institute
John Williams,
Roslin Institute

International genome mapping programmes generate vast amounts of data, with information coming out of many laboratories across the world. To make best use of this information and to enable the projects to be run efficiently requires centralised database and computing facilities and a good communications network.
The development of this infrastructure for domestic species is being handled jointly by the AFRC at Roslin Institute and INRA at their Jouy-en-Josas laboratories, partly funded by the EC "Gemimii" project.

Genes that confer disease resistance in chickens

At the Institute for Animal Health, mapping of the chicken genome is focused on genes which influence resistance or susceptibility to disease.

A linkage map of the chicken genome - which is about one-third the size of that of humans or mice - has been constructed from crosses between two lines of birds that differ markedly in their resistance to several diseases, so far 180 markers have been assigned to this map.

It is likely that resistance to many serious diseases of poultry is governed by single genes. Resistance to *Salmonella* appears to be associated with one particular region of the linkage map and additional marker loci are being generated in this region to enable isolation and identification of the putative *Salmonella* resistance gene. Isolation of this and similar genes will allow breeders to screen lines for disease resistance, and will also provide information about the mode of action of resistance genes.

Nat Bumstead,
Institute for Animal Health

Fingerprinting yeasts

The polymerase chain reaction, by which minute samples of genetic material can be greatly amplified, has been used to develop a very rapid method for characterising strains of the yeast *Saccharomyces cerevisiae*. The technique has been patented in the USA and Canada, and progress is being made to transfer the technology to a biotechnology company. Diagnostic, easy-to-use kits based on this technology have application in the brewing and baking industries and potentially in clinical diagnosis of pathogenic yeasts.

The use of yeasts in brewing and breadmaking is one of the earliest examples of biotechnology. Today's industries need to be able to characterise strains of yeasts, for example, to maintain purity as well as mixtures and ratios of strains to give particular properties, and to eliminate contaminants.

Conventional methods of characterisation are time-consuming, three to four weeks, and require skilled staff and laboratory facilities. But a new molecular fingerprinting, developed under a MAFF commission, characterises yeasts within one working day.

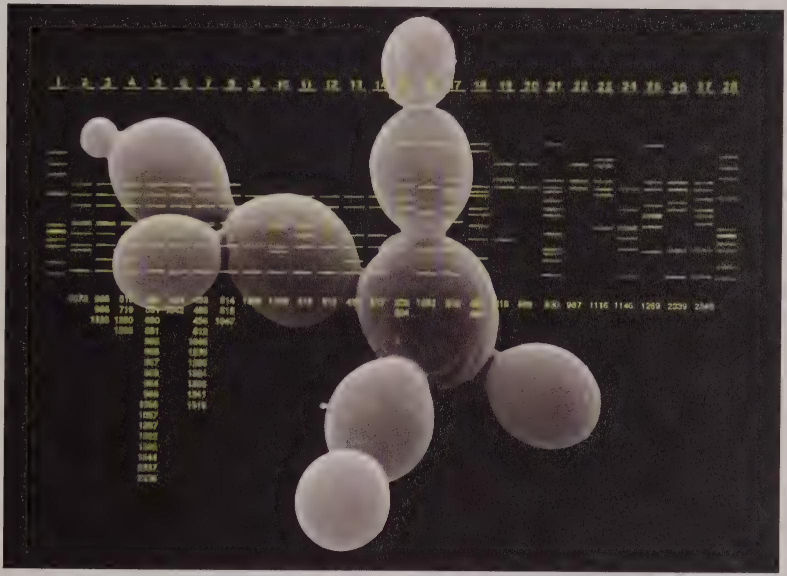
Fingerprinting is based on the polymerase chain reaction (PCR) - a technique in which specific regions of the genetic material, DNA, are replicated many times. Because of this amplification, only very small amounts of sample are required, about 0.1 mg. There is no need to purify the DNA before testing, whole cells can be used, and in excess of 50 samples a day can be screened.

This is how PCR works. The double stranded DNA in the cells is heated so that the strands separate. Short pieces of synthetic DNA are then added. These bind to corresponding complementary sequences on the single strands and act as "primers" for the synthesis of new strands, thus regenerating new double strands. This cycle can then be repeated, and after twenty to thirty cycles, the DNA is analysed by separating the pieces on an agarose gel. A characteristic pattern of bands is generated from the sequences made from the primers and these reflect the sequence of the original DNA.

Each banding pattern is like a bar code for each strain of yeast. All the baking, lager, wine, distilling and a number of ale yeasts present in the National Collection of Yeast Cultures have been fingerprinted in this way.

The key to the success of this approach is the design of the primer sequences. These have been constructed to target repeat patterns in the yeast genome, and are used in combinations. A similar approach would be expected to provide a comparable database of medically important yeasts.

Ray McKee,
Bruce Pearson,
Institute of Food Research



Yeast cells contain 16 chromosomes and about four times the ▲ genetic material of the bacterium *Escherichia coli*. Here sixty three strains of yeasts used in lager production have been genetically fingerprinted. Strains show characteristic patterns of banding of their genetic material, DNA.

Smaller than a pin head - fingerprinting can be carried out on a very small number of yeast cells (right, on tip of a plastic pipette). ▼

Gene modification and recombinant DNA technology

Novel strategies to combat plant virus replication

Molecular analysis of the mechanisms by which viruses replicate in plant cells is identifying new targets for blocking replication and making plants resistant to viral attack.

Most plant viruses are introduced into plants by vectors, such as insects, which have acquired them by feeding on other infected plants. The viruses then multiply within plant cells to produce millions of progeny virus particles and move to cells in other parts of the plant where the multiplication process is repeated. The concept of throwing molecular spanners into the works in order to disrupt virus multiplication, movement and vector transmission is attractive. The diagram shows some of the stages at which such strategies have been, or might be, deployed.

Of course, one critical stage is replication of the viral genome. If this is inhibited then the virus cannot spread. Recently, research at Imperial College has led to the world's first isolation of molecular complexes (replicases) capable of replicating plant virus RNA *in vitro*. The first was isolated from cucumber mosaic virus (CMV)-infected plants, the second from red clover necrotic mosaic virus (RCNMV)-infected plants.

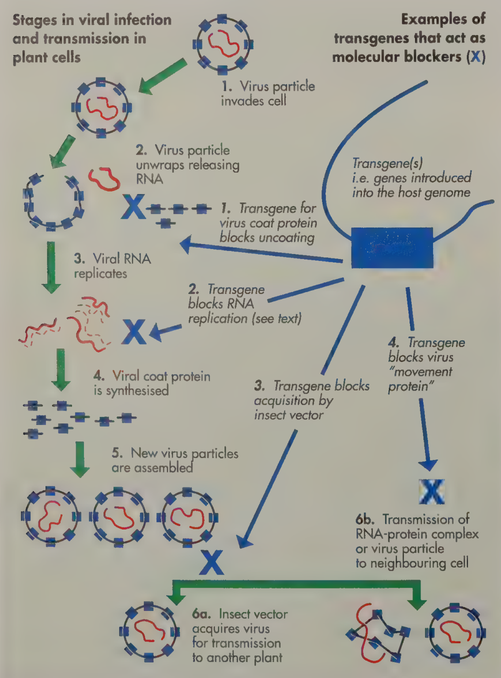
These replicases are being characterised. Each comprises not only proteins coded for by the virus but also at least one protein originating from the host plant cell. This indicates that the viruses commandeer normal protein components of the cell and use them to replicate viral RNA.

There are two implications. Firstly, this suggests that modifying the genes for the host proteins so that they produce proteins that continue to fulfil their normal functions, but are no longer recognised and available to invading virus, would be an effective method of blocking viral replication. Secondly, it provides clues to how viruses cause symptoms in plants, perhaps by diverting host proteins from their normal functions.

The host protein components of viral replicases may be targeted by several different viruses, so their modification might protect against more than one disease. The nature of the host components and how they interact with the viral products is being investigated for both CMV and RCNMV. So far, two host components from CMV replicase have been purified - there may be as many as six - and the gene for one has been cloned.

Further evidence that the modification of some host genes could protect against viral attack without impairing plant function comes from a gene *Tm-1*, originally found in wild tomatoes. It protects against tomato mosaic virus, but this resistance is overcome by viruses with abnormal replicases. One possibility is that *Tm-1* is a mutant form of a gene which normally codes for a protein that is hijacked by the virus to make viral replicase. Studies on the gene and on host proteins that interact with replicase components will aid the identification of strategies to enhance the protective effect of *Tm-1* and genes like it in other species.

Kenneth Buck,
Robert Hayes,
Imperial College of Science,
Technology and Medicine,
London.


Stages in viral infection and transmission in plant cells
Examples of transgenes that act as molecular blockers (X)
1. Virus particle invades cell
2. Virus particle unwraps releasing RNA
3. Viral RNA replicates
4. Viral coat protein is synthesised
5. New virus particles are assembled
6a. Insect vector acquires virus for transmission to another plant
6b. Transmission of RNA-protein complex or virus particle to neighbouring cell
Transgene(s) i.e. genes introduced into the host genome
1. Transgene for virus coat protein blocks uncoating
2. Transgene blocks RNA replication (see text)
3. Transgene blocks acquisition by insect vector
4. Transgene blocks virus "movement protein"
X
X
X
X

▲ Recent research has led to the first isolation of molecular complexes capable of completely replicating plant virus RNA *in vitro*. Tobacco leaves: uninfected (left) and infected with RNA polymerase transcripts of cloned cucumber mosaic virus.

Modified and novel oilseed crops for industry

Plant-derived erucic acid is used in the manufacture of nylon polymers, coatings for plastics, lubricants, inks, cosmetics and pharmaceuticals. A LINK project with industry is exploiting techniques of genetic modification to produce industrial rapeseed plants that produce high levels of this valuable fatty acid in their seed oil. Another approach is exploring how wild species naturally rich in erucic acid might be domesticated for cultivation in the UK.

The principal component of seed oil in the rape cultivars introduced into Britain in the 1970s and 1980s is oleic acid. There is virtually no erucic acid (less than 0.1%). But in the seed oil of older cultivars, erucic acid comprises up to 40-50%. Whilst not suitable for food uses, these earlier cultivars have considerable potential as industrial crops for production of erucic acid.

A five year project in collaboration with an industrial partner is aimed at producing rape plants with seed oil containing at least 90% erucic acid. This will not only increase supplies of erucic acid, but the higher level of purity will reduce the costs and environmental impact of rapeseed processing.

Erucic acid is synthesised by the stepwise addition of two "2-carbon" units to the oleic acid molecule. Erucic acid is then transferred to glycerol by three acyltransferase enzymes in order to make the triacylglycerol seed oil. One of the rapeseed acyltransferases has very low activities for erucic acid, resulting in a relatively low proportion (40-50%) of this fatty acid, even in so-called "high-erucic" rapeseed cultivars. By contrast, the corresponding enzyme in *Limnanthes* is very active, producing high levels of erucic acid and its precursor. This plant, which is also known as meadowfoam, grows wild on the west coast of the USA.

The strategy for improving erucic acid yield in rape is firstly, to use antisense technology to block the rape gene that codes for acyltransferase, and secondly, to use gene transfer techniques to introduce into rape the gene from meadowfoam that codes for its highly efficient enzyme. This involves identifying and cloning the respective genes. Longer-term it might be possible to use techniques of protein engineering to improve the performance of the rape enzyme.

Modification of the seed oil profile of plants is possible because the nature of the oil is not crucial to plant survival and growth. All oils have roughly the same energy value and are equally useful as energy reserves.

▲ Meadowfoam *(Limnanthes)* is a rich natural source of the industrially valuable oil, erucic acid. It is an excellent substitute for sperm whale oil.

Domestication of meadowfoam offers an alternative to genetic engineering. It would have the advantage of increasing crop diversity, and thus reducing the vulnerability to disease and pests associated with extensive monocultures. Research has commenced to identify ways of overcoming current limitations of meadowfoam such as low fertility and dependence on insect pollinators. Two species are known that have complementary agronomic traits which need to be combined. Modern techniques such as protoplast fusion and embryo rescue might be used with conventional breeding for improved disease resistance, synchronised flowering, etc, to develop an efficient industrial crop.

This research is part of a wider programme exploring the potential of oilseed crops as renewable sources of industrial feedstocks. Examples include production of petroselinic acid - for manufacture of detergents and plastic and nylon polymers, and lauric acid - for powder and liquid detergents.

Denis Murphy,
John Innes Centre

Tailoring plant metabolism to the needs of the food industry

A better understanding of the mechanisms of flavour development should help plant breeders and food processors to match product quality direct to market demand.

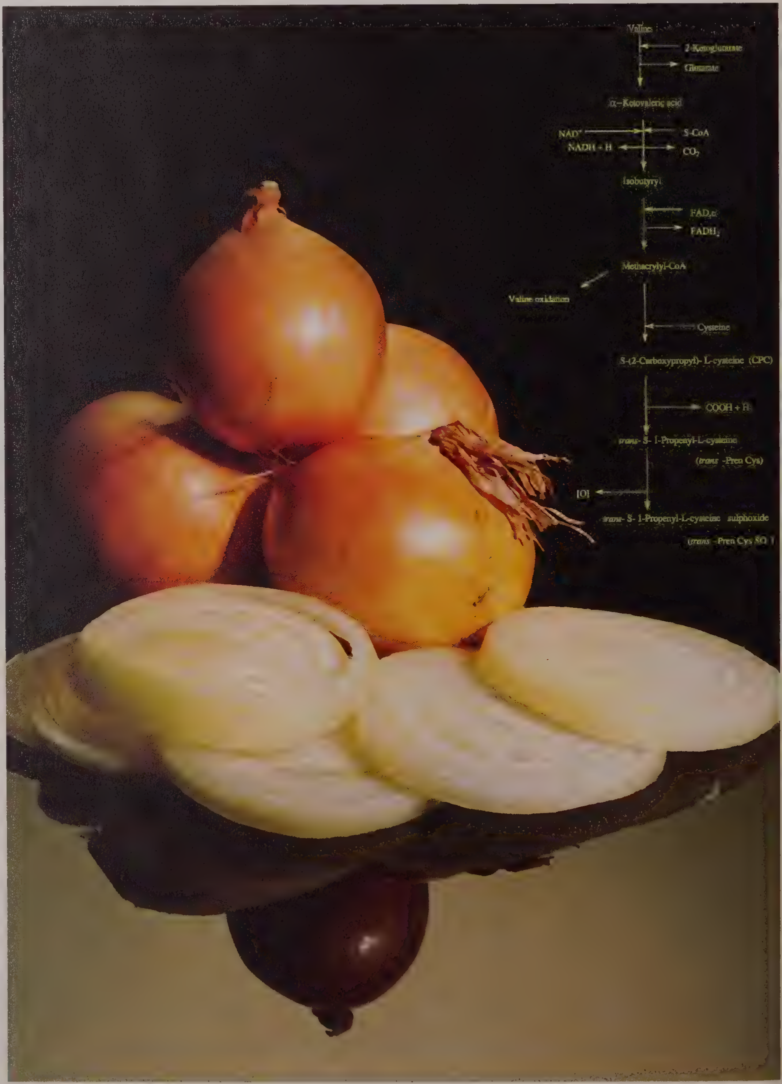
Members of the *Allium* species, including onion, garlic, leeks and chives, are widely used to flavour fresh and processed foods. Each derives its characteristic flavour from interaction of the enzyme, alliinase, with different combinations of four flavour precursors. In principle, it should be possible to manipulate this interaction to generate new flavour profiles and to fill gaps in the market. For example, the UK imports onion flakes and onion oil for use in convenience foods.

Research at the University of Liverpool is providing fundamental information about the activity and regulation of enzymes that synthesise the flavour precursors, and about the location of key stages of flavour development in plant cells. This will lay the basis for subsequent identification of the genes that determine the levels of alliinase activity and levels of the different flavour precursors so that both traditional breeding and genetic engineering might be used to manipulate flavour development.

The four flavour precursors in *Allium* species are collectively known as the alk(en)yl-L-cysteine sulphoxides. The major flavour precursor in the onion is prop-l-enyl-L-cysteine sulphoxide (Pren Cys SO), but in the mature bulb the majority of Pren Cys SO is present in a bound form as its γ-glutamyl derivative (γ-glu Pren Cys SO), when it is impervious to the action of alliinase and cannot therefore contribute to flavour. It is essential to examine the position of γ-glu Pren Cys SO in the synthesis of Pren Cys SO if flavour levels are to be manipulated.

Two possible biosynthetic routes for Pren Cys SO synthesis have been studied by using pulse labelling of intact plants with S^{35}. The pattern of labelling in individual cell fractions and specific intermediates suggested that the γ-glu Pren Cys SO was not the immediate precursor to Pren Cys SO but was formed from Pren Cys SO under the control of developmental triggers. Synthesis of Pren Cys SO occurred in the plastid and endoplasmic reticulum membrane fractions, whereas long-term storage of Pren Cys SO may occur in cytoplasmic vesicles.

Hamish Collin,
University of Liverpool



Key stages in the production of flavouring compounds are being identified, offering plant breeders and food processors opportunities to develop new flavours. ▶ (Photo: Institute of Food Research).

Animal vaccines from plants

Plant viruses can be adapted to express fragments of animal viruses, offering a potentially safe and inexpensive means of vaccine production.

Vaccines against viral diseases are made traditionally from weakened strains of the virus itself. Inevitably, there is a small risk of the virus regaining pathogenicity and causing the infection it was designed to prevent. Recently, novel vaccines have been developed in which non-infectious fragments of disease viruses are inserted into harmless animal viruses which act as carriers. The inserted fragments are adequate to elicit an immune response, but cannot cause infection. A potential difficulty with these recombinant vaccines is that the animal being vaccinated might already have encountered the carrier virus and so be immunised against it - effectively destroying the vaccine before it can work. Another limitation is that growing animal viruses to make vaccines requires costly cell culture systems.

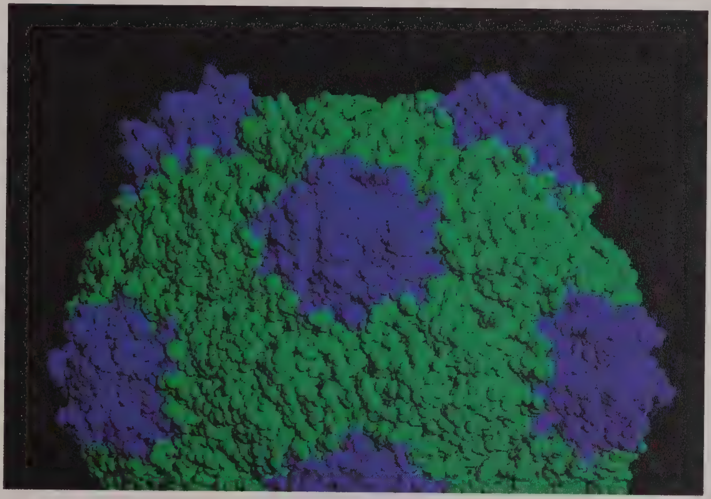
Scientists at the John Innes Institute reasoned that plant viruses might make better carriers because they overcome problems of prior exposure of animals, and they could be produced simply and cheaply in plants.

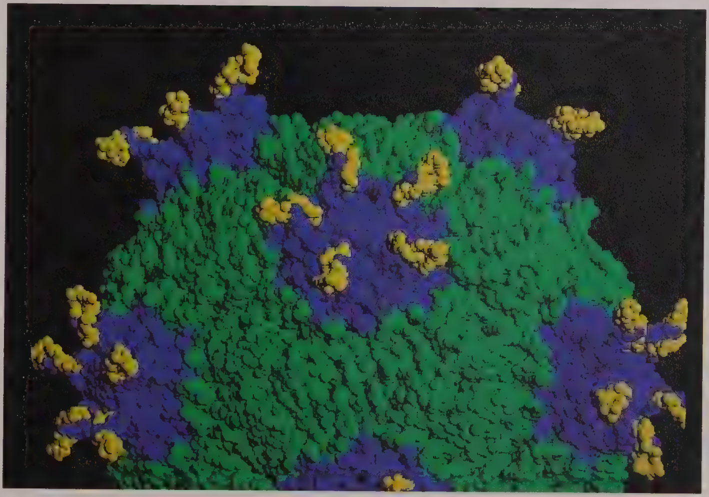
Now, in collaboration with scientists in the USA and with support from the Agricultural Genetics Company, the researchers have designed and produced a harmless plant virus carrying a fragment of the foot-and-mouth disease virus (FMDV) which is known to elicit an immune response.

Key stages in the research were the identification of a suitable plant virus and location within it of a region amenable to substitution by the FMDV fragment. A procedure was developed to substitute the portion of plant virus genetic material by that coding for the FMDV fragment in such a way that the modified plant virus remained capable of multiplying in plant cells.

The well characterised cowpea mosaic virus was chosen as the carrier and part of its S protein which is known to be particularly exposed on the surface of the virus was targeted. Part of the gene for this S protein was successfully substituted with that for the FMDV fragment, generating cowpea mosaic virus particles that carry the FMDV fragment on their surface. The ability of these modified viruses to elicit production of protective antibodies against FMDV is now to be tested in collaboration with the Institute for Animal Health (Pirbright Laboratory).

George Lomonossoff,
John Innes Centre





▲ Computer-generated images of (top) the cowpea mosaic virus and (bottom) the virus modified so that part of each of the copies of its surface component S protein now carries an antibody-eliciting fragment (yellow) of foot-and-mouth disease virus.

The Agricultural Genetics Company Ltd has applied for intellectual property rights on this invention and plans to develop it on behalf of AFRC.

Plant molecular biology

The Council's £14M programme on Plant Molecular Biology (1989-1992) helped to establish the UK as an internationally competitive nation in this field. UK scientists are amongst the world leaders in gene identification, mapping and isolation technologies; and many technologies developed with model plant species such as *Arabidopsis* are now amenable for application in crop species.

In addition to its scientific success, the programme provided a cost-effective use of resources, strengthened collaborations, avoided duplication of effort and encouraged the return of some of our best young scientists from overseas.

Building upon these successes, the Council has launched a second coordinated programme with particular emphasis on the transfer of technology to crop plants.

A total of 44 projects are funded under the new programme. This involves researchers at 21 universities and institutes. The programme is coordinated by Chris Leaver FRS, University of Oxford, and Caroline Dean, John Innes Centre. Two examples are outlined below.

Genetic regulation of the development of photosynthetic tissue in maize leaves

A mutant of maize has been isolated in which the normal pattern of leaf development is disrupted. Genetic analysis of this mutant will provide valuable information about how plants regulate tissue differentiation during development. Also because the mutation affects photosynthesis, its characterisation will improve understanding of biochemical mechanisms that regulate photosynthesis in C4 plants such as maize.

In normal maize, most of the leaf is made up of two types of cells which interact to provide the photosynthetic capability. These are the bundle sheath (BS) and mesophyll (M) cells. They differ morphologically in the type and arrangement of their chloroplasts, and enzymatically in that they contain different enzymes involved in the fixation of carbon dioxide through the C4 pathway of photosynthesis. These two types of cells develop together in a coordinated manner. But in a mutant, *bsd1-m1*, the BS cells fail to develop, while the rest of the cell types in the leaf develop normally. Photosynthesis in the mutant is also greatly impaired as there are no characteristic BS chloroplasts and no BS cell-specific photosynthetic enzymes.

The *bsd1-m1* mutant was created using a maize transposon - a mobile piece of DNA that moves from position to position within the maize chromosomes, disrupting the activity of genes when it inserts itself into them. In the case of *bsd1-m1*, this transposon has inserted in such a way that it prevents expression of a gene that affects differentiation of BS cells. Research is underway to isolate this gene by using a molecular "hook" to pull out the transposon and with it the disrupted gene. This will allow identification of the gene and facilitate its cloning and further characterisation. This should lead to a greater understanding of events involved in cellular differentiation and of mechanisms that regulate the agronomically important C4 pathway of photosynthesis.

***Jane Langdale**, University of Oxford.*

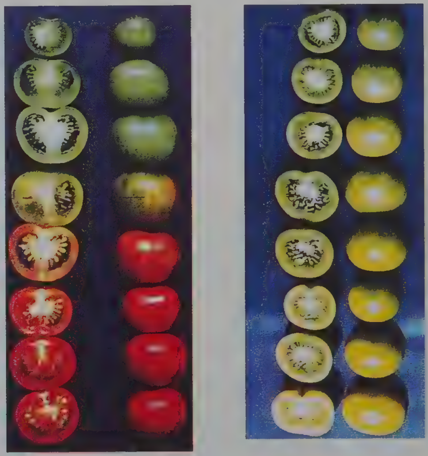
Genetic regulation of fruit ripening

Significant progress has been made in understanding the molecular biology of tomato fruit ripening. Genes coding for enzymes involved in the ripening process, such as cell wall degrading enzymes and those involved in pigment and ethylene biosynthesis, have been identified and their specific functions explored, together with the nature and role of associated regulatory genes.

The results to date are providing fundamental information concerning the mechanisms of gene regulation in plants and suggesting strategies for the modification of gene expression in transgenic plants.

The *ripening inhibitor (rin)* tomato mutant is deficient in a variety of responses and processes associated with normal fruit ripening. For example, mutant fruit exhibit impaired synthesis, and response to, ethylene and have incomplete development of flavour and aroma profiles. The fruit fail to soften appreciably over a period of several months. The *rin* phenotype is thought to arise from a mutation in a regulatory gene. Screening a new fruit cDNA library with probes derived from normal and *rin* fruit identified six cloned mRNAs which accumulate during normal ripening but are present at reduced levels in the *rin* fruit. These clones have been sequenced and the accumulation of their mRNAs during ripening characterised. Current research is directed towards assigning a role to each gene product in the different processes of ripening, for example, their potential involvement in softening, pigment change or generation of changes in flavour and aroma of the ripe fruit. This is being achieved by turning off the expression of each of these ripening genes in genetically engineered tomato plants in order to assess the effect they may have on fruit ripening. Recent results suggest that the *rin* phenotype arises from a mutation in a regulator gene.

***Don Grierson**, AFRC Research Group in Plant Gene Regulation, University of Nottingham.*



▲ Stages in the ripening of wild-type tomato (left) and *rin*, an extreme ripening mutant.

The molecular biology of stem cells

The Council's coordinated programme on stem cells involves researchers in nine universities, the Centre for Genome Research at Edinburgh, and four institutes. A total of 46 projects are supported in the programme which is coordinated by Hugh Dickinson, University of Oxford, and Rosa Beddington, Medical Research Council. Two examples are given below.

Cells that control self-renewal and repair in skin

The epidermis, the outer layers of skin, is constantly renewed as superficial cells are lost and are replaced by new cells that are pushed upwards. In human skin, it takes about a month for cells to move from the base layers to the surface. This process relies upon the presence at the base of the epidermis of cells capable of division and self renewal so that at cell division one of the progeny retains the parental phenotype. However such putative stem cells have not been identified unequivocally in the epidermis - mainly because there has not been a satisfactory assay for them.

A better understanding of cellular interactions that control the renewal of skin cells is of fundamental importance, and has direct implications for studies on wound healing and skin grafting.

Recently, a model system has been developed which has indicated for the first time that the underlying cells of the dermis are required for the maintenance of self replication of keratinocytes of the epidermis. This suggests a control mechanism resembling that of blood cells, where stem cell renewal depends upon another cell type in the bone marrow.

Research is aimed at identifying the molecular interactions between keratinocyte stem cells and accessary cells in the dermis. This involves, for example, identifying the growth factors and inhibitory molecules that regulate the stem cells and understanding how the balance between them is modulated.

***Margaret Stanley**, University of Cambridge*

Molecular basis of genomic imprinting in plants

Whether a gene is inherited from the male or female parent can affect how it is expressed in the offspring. This phenomenon of genomic imprinting is very important in animal development but is less recognised in plants. One exception, however, where the correct balance of maternal and parental genomes is crucial in plant development is in the formation of the endosperm.

Research is identifying the genes modified in *Zea mays*, and the molecular mechanism of imprinting. This will not only provide fundamental insights into gamete formation in plants but will also have important agronomic implications. Endosperm development is important for grain formation in cereal crops, and therefore genomic imprinting may play an important role in determining crop yields. A better understanding of genomic imprinting might also suggest strategies to improve crop breeding. Some commercially-important wide-hybrids sometimes fail because of aberrant endosperm development.

***Hugh Dickinson**,*
University of Oxford

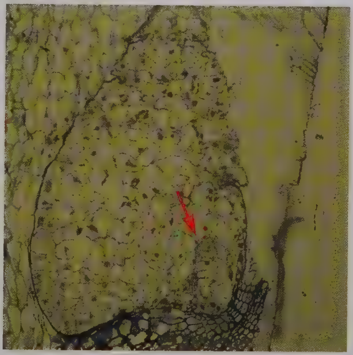


Figure 1

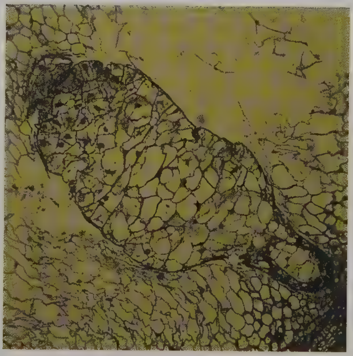


Figure 2

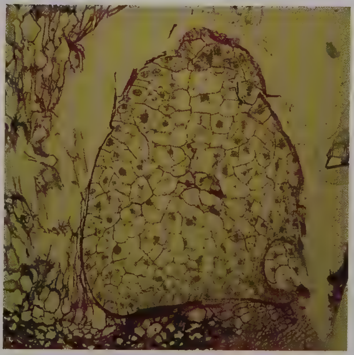


Figure 3

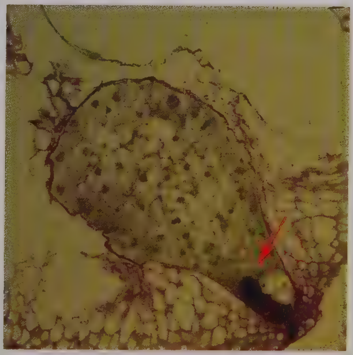


Figure 4

▲ Four days after pollination the developing maize embryo (arrow, Figure 1) is invested by a multicellular endosperm. Following pollinations resulting in "wrong" combinations of imprinted nuclei, a misshapen endosperm is formed (Figure 2) containing fewer cells. The use of carbohydrate-specific probes (red staining in Figures 3 [normal] and 4 [aberrant]) shows unusual cell-wall thickenings at the interface between the embryo and the aberrant endosperm (arrow, Figure 4).

Recombinant enzymes for the paper and animal feed industries

Hemicellulase enzymes have enormous commercial potential. Recombinant DNA technology is being used to study the structure and function of these enzymes. Besides showing how they may be produced on a large scale, this is indicating strategies for enhancing enzyme activity and for designing novel enzymes with new and improved properties.

Microbial cellulases and hemicellulases that hydrolyse plant cell walls have a key role in herbivore digestion and in recycling plant biomass via natural decay. They also have valuable uses in pulp and paper production, brewing, textile manufacture and as enzyme supplements for animal feeds. Current commercial use of cellulases and hemicellulases relies on often poorly-defined mixtures of naturally-occurring enzymes; improvements are hampered by a lack of understanding of the role of each enzyme in cell wall hydrolysis, and by the difficulty of producing large amounts of pure enzyme.

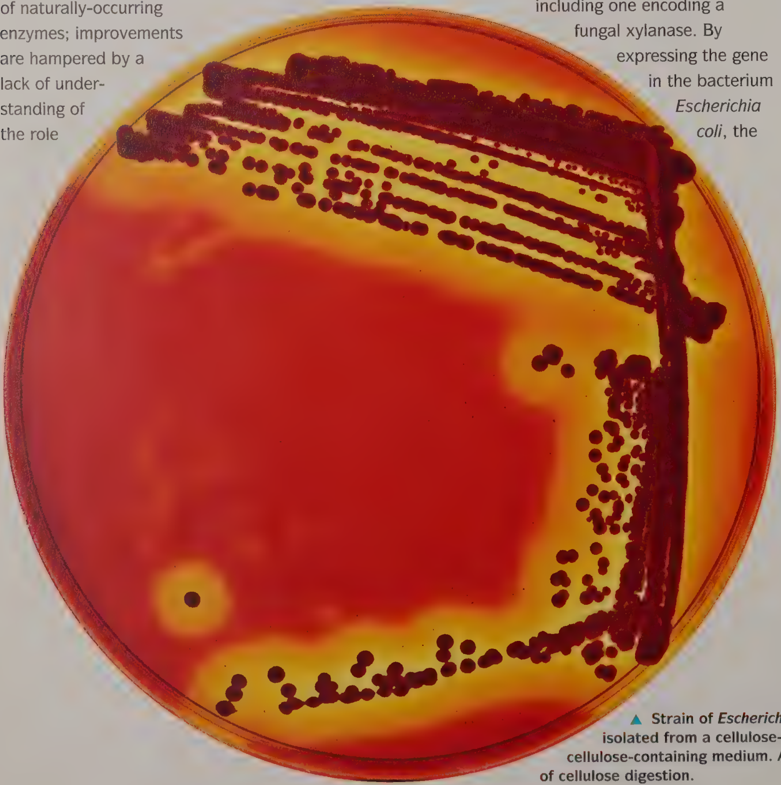
Xylanase (a type of hemicellulase) offers paper manufacturers an environmentally cleaner alternative for removing lignin from pulp than conventional bleaching with strong alkali and chlorine derivatives. Contamination of native xylanases with cellulases that adversely affect paper quality can be a problem.

In the poultry industry, enzyme supplements containing xylanase and cellulase-related enzymes are routinely added to cereal-based feeds to promote breakdown of cell wall material which otherwise would remain undigested, leading to increased viscosity of intestinal contents and impaired digestion, nutrient assimilation and feed conversion. But the site and precise mode of action, and the optimal composition of the enzyme supplement remain undetermined.

A Linked Research Group between scientists at the Babraham Institute and the University of Newcastle upon Tyne is studying the molecular structure and function of microbial cellulases and hemicellulases. Recently, genes coding for a number of hemicellulases have been isolated, including one encoding a fungal xylanase. By expressing the gene in the bacterium *Escherichia coli*, the scientists are able to produce large quantities of an extremely active xylanase that is free from contamination by cellulase. This enzyme has potential value for bleaching paper pulp and as a supplement in poultry feed. In feeding trials, this single enzyme proved as effective as the mixture of enzymes contained in some current commercial supplements, indicating that, in future, "designer supplements" could be made from combinations of recombinant enzymes encoded by cloned genes.

Other cellulases and hemicellulases will almost certainly find industrial uses. The primary sequences of different enzymes are being compared to establish how structure relates to biological function. Many of these enzymes are modular, containing one or more catalytic domains linked to a non-catalytic cellulose-binding domain by a flexible hinge region. One area of interest to the researchers is the effect of the binding regions and linker sequences on the action of the enzymes on paper pulp, for example. This could indicate how enzyme activity might be modulated by genetic engineering, and new enzymes designed for specific industrial purposes.

Harry Gilbert,
University of Newcastle upon Tyne
Geoffrey Hazlewood,
Babraham Institute

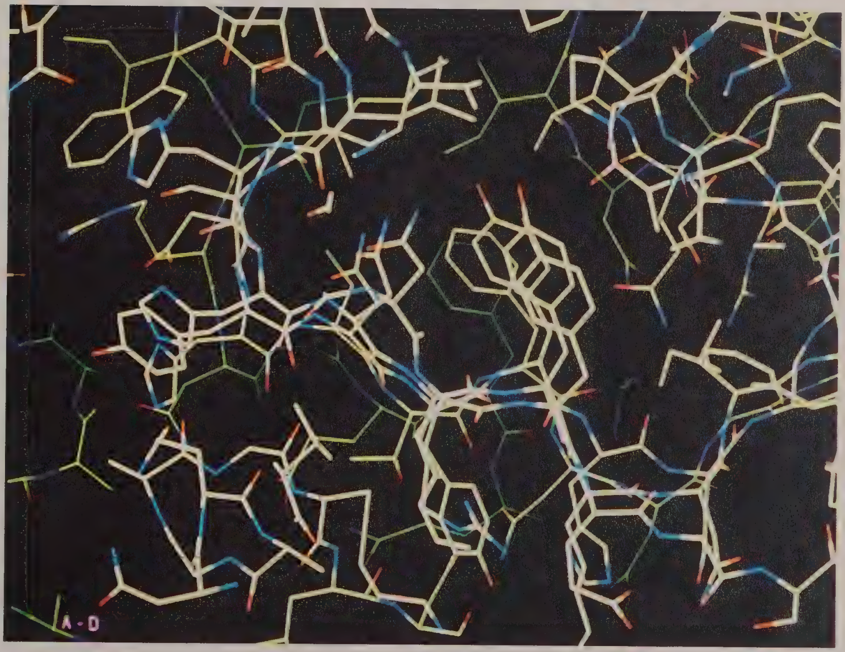


▲ Strain of *Escherichia coli*, expressing a cellulase gene isolated from a cellulose-digesting bacterium, cultured on a cellulose-containing medium. Absence of the red dye is indicative of cellulose digestion.

Molecular structure and recognition

Novel structural motif in pectate lyase

Scientists at the Institute of Food Research have achieved a European first by solving the three-dimensional structure of the enzyme pectate lyase. This breakthrough is important to the food industry since it should open up ways of favourably modifying the use of pectin as a gelling agent and of improving the process of fruit juice clarification.



▲ **Side-chain stacks within the interior of the β-coil include stacks of isoleucines, asparagines and aromatic residues. The regularity of the structure is striking as is the close packing of the aromatic residues.**

Pectate lyases are secreted by bacteria and fungi and are important because they initiate soft-rot diseases in plants by degrading polygalacturonate, a major component of plant cell walls as well as being involved in breaking down the complex carbohydrate, pectin.

The structure of the pectate lyase from *Bacillus subtilus* has been solved and refined at 2.5Å resolution. The most striking characteristic of this enzyme is the new parallel β-coil architecture in which the polypeptide chain coils around to form a parallel β-sandwich with a very regular arrangement of side-chains in the interior. Inhibitors of pectate lyase may be valuable for the protection of crops against pathogens. The new architecture may lead to novel strategies for displaying antigenic loops as well as providing a new fold which may find many new biotechnological uses.

Proteins may be classified according to their secondary structure content and topology as: α-helical, β-sheet, α/β or α+β. The all β-proteins are mostly antiparallel and all parallel β-structure was considered to be unstable, partly because it had not been observed, but also because the non-bonded interactions in a parallel-β are less favourable than those of antiparallel-β. However, pectate lyase is a parallel β-protein with a new architecture; the β-coil. The consequence of coiling the polypeptide chain around into a structure resembling a spring is the striking regularity of the side-chain contacts that can be made both within and on the surface of the molecule (see figure). Especially striking is the stack of aromatic groups, a favourable packing arrangement not often allowed by the main-chain geometry of globular proteins but seen in double stranded DNA.

Pectate lyase catalyses the cleavage of α-1,4 linked galacturonosyl residues of pectate by a β-elimination. Pectin and pectate lyases are homologous but pectate lyases are distinguished by a requirement for calcium and a higher pH optimum. The calcium binding site of the pectate lyase from *B. subtilis* is at the junction between the major spring domain, which consists of eight turns of β-coil, and a second domain formed by three loops which extends from turns one, three and four of the basic β-coil motif. The calcium binding site consists of three aspartic acid residues. It is expected that the calcium at this site will bind to the carboxy-group of the pectate substrate.

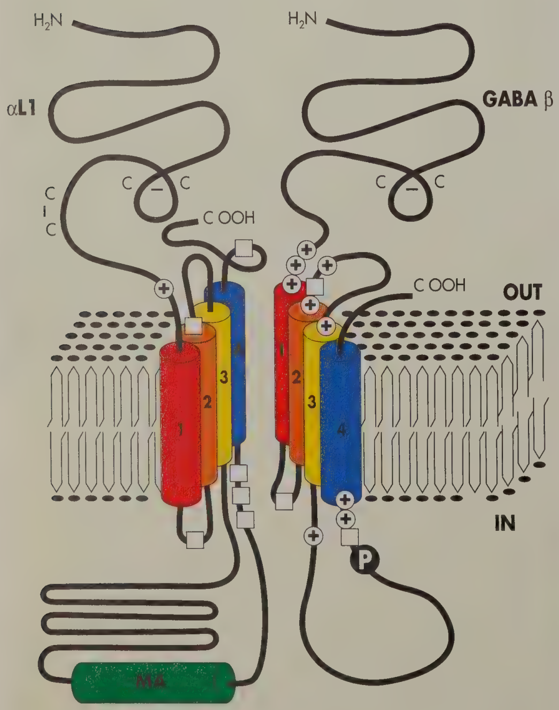
Richard Pickersgill,
Institute of Food Research

New targets for pesticides identified

Research is providing new options for the rational design of safer agrochemicals.

Many pest control agents rely for their effectiveness on blocking the passage of chemical signals between the nerve cells of invertebrates. An important family of receptor molecules in cell membranes that receive and relay chemical signals is being characterised. Understanding the functions of different regions of these molecules should enable the design of pesticides specifically targeted to block signal transduction. It might also suggest new strategies for combating the evolution of resistance to pesticides - a serious problem with some pests.

Attention has focused on receptors for two fast acting primary chemical signals, acetylcholine and GABA (gamma-amino butyric acid). The receptors, each composed of five subunits, span the outer membrane of the nerve cell. On recognition of the appropriate signal, each receptor briefly opens an aqueous channel across the otherwise waterproof membrane through which ions can flow, thereby passing information from one cell to another.



▲ Family likeness: Schematic representations of neurotransmitter binding subunits of locust (αL1) nicotinic acetylcholine receptor and *Drosophila* (β) GABA receptor. Four membrane spanning regions are shown as cylinders. In each case, the long N-terminal extracellular region contains the neurotransmitter binding site. MA is a predicted amphipathic helix unique to nicotinic receptors.

In collaboration with the MRC Molecular Neurobiology Unit in Cambridge, the gene coding for the acetylcholine receptor of locusts has been isolated and sequenced. The chemical specificity of regions that bind the primary signals and those responsible for making the cross-membrane channel have been characterised in detail. Also located was a site that binds nitromethylene insecticides. This was the first insecticide molecular target of this class to be characterised to this level of molecular detail. Work is also underway on nematode acetylcholine receptors, the molecular targets of anti-parasitic drugs for human and animal use, such as levamisole.

Recently, in a joint venture with E I duPont de Nemours and Co of the USA, genes coding for the GABA receptors in the fruit fly *Drosophila* have been cloned and sequenced. The wealth of genetic information available for this organism and access to mutants resistant to insect control agents is providing new insights into resistance mechanisms.

The diagram shows the strong overall structural similarities between the acetylcholine and GABA receptor subunits. However, it is the differences between them that yield the most interesting information. For example, it should be possible to understand in molecular terms why these two receptors are targets for chemically distinct pesticides. Basic information about the molecular activity of pesticides and their selectivity is also a prerequisite for designing effective and highly specific pest control agents that do not harm beneficial invertebrates.

David Sattelle,
Babraham Institute

▲ Babraham † and duPont ‡ scientists collaborating on the characterisation of receptor molecules: (from left) J Rauh ‡, D Sattelle †, R Flattum ‡, R B Heap †, J Pierce ‡ and G Hollingshaus ‡.

Natural molecules to enhance stability of industrial foams and emulsions

Fundamental research into the behaviour of biological molecules at interfaces indicates that natural components might replace synthetic stabilisers and emulsifiers for the food and pharmaceutical industries.

Many foods are composites in which particles are dispersed. For example, foams (air bubbles in water) are found in cakes, snack foods, ice creams, mousses, etc, and emulsions (oil droplets in water and *vice versa*) in mayonnaise and dairy spreads. Many cosmetic and pharmaceutical preparations are also emulsions.

Proteins can be effective stabilisers of foams and emulsions by adsorbing and interacting at the water-air, or water-oil interface. In such cases the stability of dispersions depends on the maintenance of viscoelastic layers of protein that form at the interfaces between the different components. However, the structural integrity of this adsorbed protein layer can be impaired by small surfactant molecules such as lipids that are able to locate between protein molecules effectively breaking their interactions and weakening the layer.

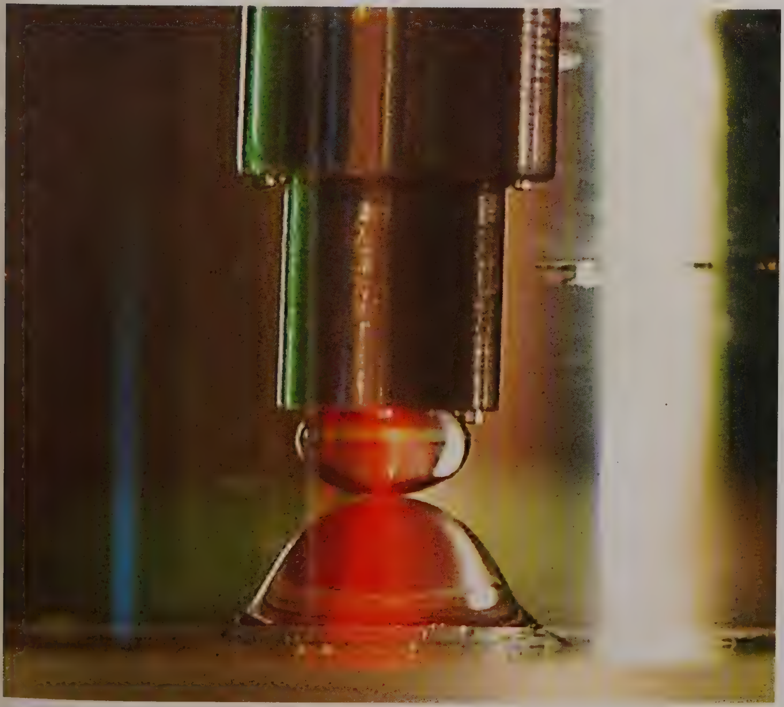
Two different approaches for enhancing dispersion stability are being investigated, both deploy naturally occurring molecules. The first involves small molecules that can crosslink proteins at the interface and so strengthen the adsorbed layer against disruption. The second uses a lipid-binding protein to "mop up" molecules that would otherwise weaken the protein layer.

The iso-α-acid fraction from hops has been found to stabilise protein foams by crosslinking. This work will be extended in a collaborative DTI-funded LINK project, involving four commercial brewers and the Brewing Research Foundation International, in which the six isomers of the acids are being separated and the stabilising properties of each will be characterised. Foam stability is measured by its conductivity: the better the dispersion, the smaller the air bubbles, the more the connections between them and so the higher the conductivity. As the dispersion collapses and bubbles coalesce, conductivity declines. These results are correlated with measurements of the extent of hop acid-induced crosslinking in the adsorbed protein layer measured using a laser-based fluorescence photobleaching technique called FRAP.

Studies are being broadened to evaluate other natural functionality enhancing molecules. For example, tartaric acid may exert an electrostatic bridging role, as might some polysaccharides and amino acids. This builds on earlier work demonstrating that mixtures of positively and negatively charged proteins formed strong electrostatic interactions in the adsorbed layer. The properties of the hop acids and these other molecules are also being investigated in emulsions.

Collaborative research with French scientists has shown that protein-protein interactions in the adsorbed film in foams can be stabilised by removing competing surfactants. The properties of a lipid-binding protein, puroindoline, isolated from wheat by the French group, have been examined both with lipid analogues and in beer. Mechanisms for its mode of action have been proposed, and further investigations and possible exploitation is being pursued with industry.

David Clark,
Institute of Food Research
Didier Marion,
INRA, Nantes, France



▲ **Laser interferometry is used to measure interactions within and thickness of adsorbed protein layers in a thin film between two air bubbles in a model foam.**

Biological materials as industrial feedstock

The biology and economics of fuel crops

Field experiments are being used to identify potential fuel crops most suited to UK conditions and industrial requirements.

Several species of perennial, fast-growing grasses are possible candidates for development as energy crops on set aside land in the UK. One of the best known is the Asian woody grass, *Miscanthus*. An experimental area measuring 24m x 50m has been established as part of the EC Network on *Miscanthus* at the Institute of Arable Crops Research. Work has commenced to identify basic physiological characteristics that will be important in determining the yield and potential value of *Miscanthus* as a UK crop. For example, measurements of nutrient demand will allow assessment of long-term impact on soil fertility and the implications both for crop management and for eventual return to food production of land used for *Miscanthus*. *Miscanthus* belongs to the *Graminae* and the extent to which it might act as a reservoir for diseases of cereals such as wheat, or itself be a victim of wheat pathogens, is being investigated.

Two American grasses, the wetland grass *Spartina* and the prairie grass *Panicum* (switch grass) are also being tested for their performance under UK growing conditions; and *Rye* is being examined because of its potential to produce high yields of dry matter earlier in the year with relatively low inputs of nutrients.

In addition to EC funding, this research is supported from the DTI through the Energy Technology Support Unit (ETSU) and is conducted in collaboration with ADAS.

The profitability of electricity generation from arable wood crops has been examined and mathematically modelled. This model considers the factors that exert a major influence on profitability over about twenty years.

An important decision for the farmer is whether the investment in generating equipment will yield a profit over the life of the enterprise. The model identifies the maximum affordable annual generating costs, based on consideration of predicted crop yields, generator efficiency, price paid to the farmer for electricity, capital costs of harvester and cost of cutting.

▲ **In the Spring, shoots arise from underground rhizomes. At present establishment costs are high but cost reductions will take place with large scale production.**

▲ **Yields of *Miscanthus* in the UK are expected to be c. 20t/ha. Full productivity is expected to take up to 3-4 years from planting, and to remain high for 15-20 years. (Photograph courtesy of Dr N. El Bassan, FAL, Braunschweig)**

Eric Audsley,
Silsoe Research Institute
Dudley Christian,
Institute of Arable Crops Research

Plant fibres

Fundamental research on the mechanical properties and fracture mechanics of plant fibres - aimed, for example, at understanding the nature of the bonds between fibrous and non-fibrous material and how they are broken - is being conducted in parallel with projects in the LINK programme "Crops for Industrial Use". Together, these approaches are providing a basis for improving fibre crops, and for developing new processing technologies and industrial applications.

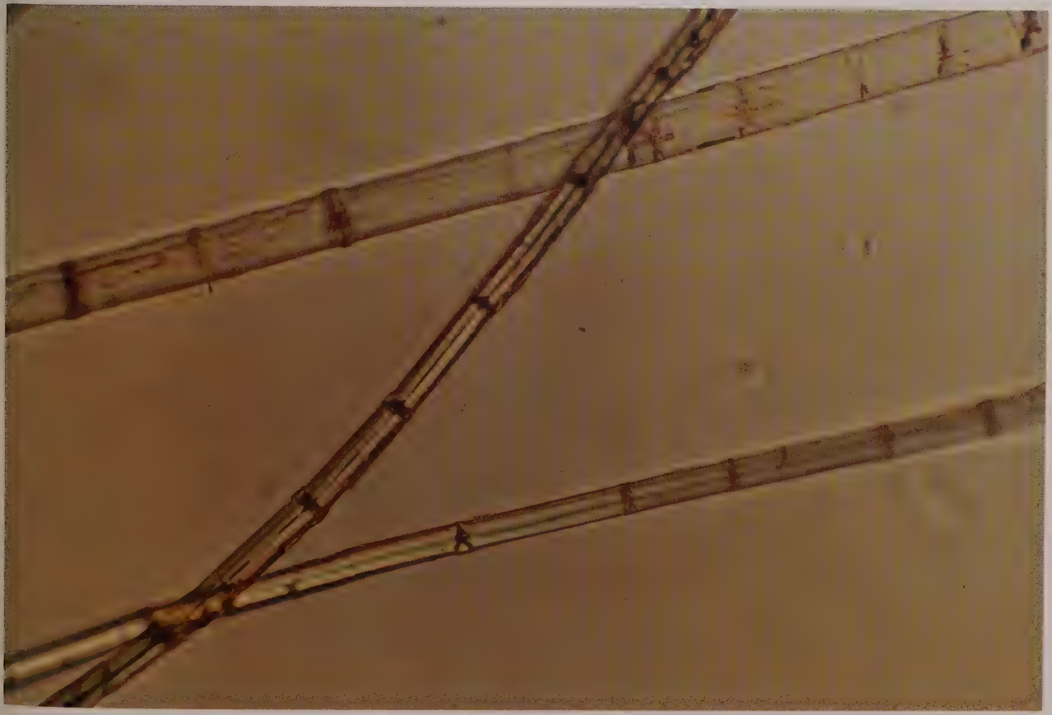
A market study has identified several potential outlets for fibres extracted from linseed straw. These include soil erosion control blankets, speciality paper pulps, industrial absorbents, linings and panelling for vehicles, and as a replacement for asbestos fibre in fibro-cement building products.

Some uses are being explored experimentally with industrial partners. For example, a matting made from linseed fibre in collaboration with Gaskell Textiles Ltd, is about to be field tested for its effectiveness as a biodegradable blanket for preventing soil erosion. Collaborative research with Compak Systems Ltd has shown that the non-fibrous "shiv" from linseed straw can be milled and converted into board of similar strength to conventional chipboard, but with a tensile strength of more than twice that of a similar board made from wheat straw.

Emphasis continues to be placed on obtaining a better understanding of how the physical characteristics of the plant affect both fibre behaviour during processing and fibre quality. Trial samples of fibre, produced in laboratory scale processes, are being used to evaluate the effects of plant variety, nutrient regimes and sowing density. It might be expected that cultural conditions such as high sowing density and high nutrient applications would result in fibres that are respectively thinner and elongated. How this influences the mechanical properties of the fibres will be explored.

Industry requires efficient methods for extracting fibres without damaging them. Enzyme treatment to weaken the bonds between the fibres and other components of the stem is an attractive option. Studies of the structural biology of plant stems will provide clues as to which enzymes may be most suitable for fibre separation.

David Bruce,
Harry Gilbertson,
Silsoe Research Institute
Jane Rickson,
Silsoe College
David Johnson,
University of Leeds



▲ Single seed-flax fibres produced from linseed straw by prototype decortication equipment developed at Silsoe Research Institute. (Image by kind permission of University of Leeds, Department of Textile Industries.)

Process control and optimisation

Optimisation of glasshouse environments

Research on dynamic systems for controlling the environment in glasshouses and advances in understanding the physiological response of plants to their environment have led to a new philosophy for controlling conditions to optimise profitability.

In most commercial glasshouses, microprocessor controllers maintain temperature, carbon dioxide concentration and humidity at fixed levels, or within set bands, according to the stage of crop development.

Profits might be increased, however, by more flexible systems in which conditions are modified in response to the plants' requirements and responses, external climatic conditions and economic factors. For example, tomatoes, lettuce and chrysanthemums respond to *average* temperatures, so savings might be made by allowing temperatures to fluctuate within say ± 2-4°C.

This new approach is based on mathematical models of how plant growth and yield are influenced by the environment, and of the engineering inputs required to achieve that environment. In each case value/cost figures are incorporated, allowing profitability to be optimised by selecting the point of maximum difference between crop value and environment cost.

Models have been constructed to quantify the inputs of energy and carbon dioxide (CO_2) required to control the glasshouse environment. Photosynthesis and the partitioning within the plant of photosynthetic products have also been modelled.

These models have been used to develop a control program which finds values of individual environmental variables which maximise the financial margin between crop value and the cost of environmental control. The first of this new generation of control strategies will be tested shortly, with support from the Horticultural Development Council, at a commercial nursery.

Interactions between temperature, CO_2 concentration and humidity are taken into account in a multivariable greenhouse model which has been developed. This is being used as the basis for developing a simple, robust model suitable for use in control. Research is characterising the constraints in automated control systems, such as greenhouse response time and deviation from the predicted environment conditions.

The concept of modulating humidity to reduce chemical inputs and minimise water consumption without impairing quality and yield is being explored as part of an EC programme on Intelligent Management and Control of Greenhouse Production Systems. Options are to prevent condensation and the risk of fungal attack, thus decreasing reliance on fungicides, matching water supply more closely with demand, and recirculating nutrients to avoid discharging fertiliser into the environment.

▲ **Models have been constructed to control the glasshouse environment which investigate interactions between temperature, CO_2 concentration and humidity.**

Bernard Bailey,
Silsoe Research Institute
Ken Cockshull,
Horticulture Research International
Peter Young,
University of Lancaster

Integrated systems of pest control

A novel method is being used to identify volatile compounds in flowers that are recognised by bees and stimulate foraging behaviour. This is just one example of studies of the chemical ecology of insects that are aiding the design of environmentally-friendly methods of pest management.

A key objective of modern pest control strategies is to minimise impact on the environment, for example on beneficial insect species, without impairing the cost-effectiveness and efficiency of pest management. Considerable effort is being made to develop integrated systems in which the use of chemical pesticides is combined with natural control agents such as the predator enemies of pests, and other natural control systems such as the attractants and repellents that influence plant/insect interactions.

Naturally occurring behaviour-modifying chemicals known as semiochemicals are already being exploited in crop protection for pest monitoring and control by disrupting insect mating behaviour. Other uses are showing great promise, e.g. in dispersing insect pests away from the crop (alarm pheromones), deterring them from eating crop plants (antifeedants), or luring them into traps or to sites where they can then be destroyed (aggregation and sex pheromones). More needs to be known about the chemistry of natural attractants and repellents and other biologically active compounds in crop plants and their effects on pest and beneficial species.

By using a sensor attached to an insect's antenna in combination with gas chromatography, it is possible to identify compounds that induce a response in the insect. As part of a large MAFF (PSD) funded project, this coupled approach has been refined so that responses from individual nerve cells can be incorporated. Now, for the first time, single cell recordings from honey bees are showing specificity to particular chemical structures, as opposed to the previously held view that generalist receptors predominate. A further novel development, coupling gas chromatography with simultaneous measurement of neurophysiological and behavioural responses, is being used to investigate odour cues in oilseed rape that assist the bees in recognising the flowers, and that stimulate foraging.

After an initial conditioning by exposure to the test sample, the bee is induced to extend her proboscis by the application of sugar solution, followed by a final reward with the solution. Test samples include individual components and the total rapeseed flower volatiles obtained by air entrainment. There is clear evidence of a predisposition to certain structural types in terms of the compounds to which the bees respond.

This new research is being conducted in collaboration with INRA and CNRS in France. In addition to its contribution to integrated pest control, this study will also provide important information about how plant/insect relationships might be altered in new genetically modified oilseed rape plants.

John Pickett,
Institute of Arable Crops Research

◀ **The honey bee can be conditioned, by use of a sugar reward, to extend its proboscis in response to flower volatiles, allowing studies on activity of individual components separated by gas chromatography.**

Technology interaction

The Council attaches great importance to technology interaction with the industries it serves. The main components are direct fully-funded contract work in areas of mutual interest, collaborative projects and programmes, and technology and information transfer leading to innovation. Examples are given here and elsewhere in the Report, for example, on pages *11, 15, 20, 23, 24, 34* and *41*.

External income

Council conducted an internal review of its technology interaction mechanisms at the end of 1992. It concluded that technology interaction should have a much higher profile in the Council's affairs, that AFRC science and technology should be marketed more aggressively than at present and that the AFRC's capability in this area should be strengthened. Specific new initiatives include:

- Improving staff awareness of the potential of intellectual property
- Introducing incentive schemes
- Reviewing institute commercial units
- Strengthening the central technology transfer capability
- Introducing measures to monitor technology interaction.

Council attaches equal importance to the transfer of technology which can be protected, exploited and produce a financial return, and to the transfer of information which cannot or need not be protected but which results in the incremental increase in know-how which continues to benefit the agricultural and food industries. Council has set up a Committee which, on a continuous basis, will determine new technology interaction policies, recommend additional mechanisms aimed at improving innovation processes and monitor progress towards objectives.

Major industrial collaborators during 1992/93 included:

Agricultural Genetics Company Ltd
BP International Ltd
BP Nutrition Ltd
British Technology Group
Ciba-Geigy Agrochemicals
duPont (UK) Ltd
Germinal Holdings
ICI plc
Intervet plc
Pharmaceutical Proteins Ltd
Pitman-Moore
SmithKline Beecham plc
Sigma Tau Pharmaceuticals
Unilever plc

LINK

AFRC is active in the Government's LINK scheme, both as a programme sponsor and, through its institutes, as the academic partner in specific projects. The Council now sponsors ten of the thirty two programmes approved to date, with a total commitment of £5.8M.

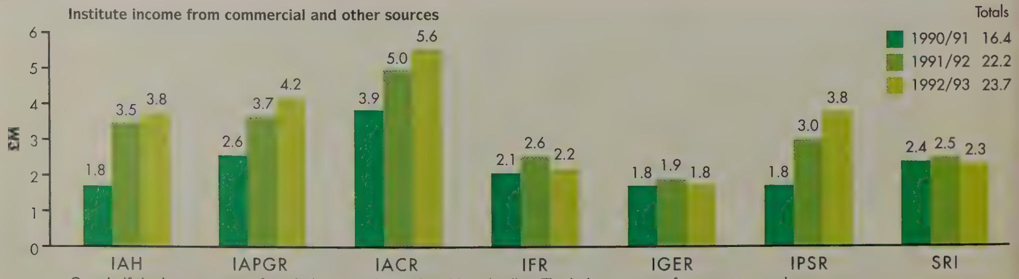
	AFRC Commitment £K
Control of Plant and Microbial Metabolism	300
Protein Engineering	830
Eukaryotic Genetic Engineering	500
Molecular Sensors	250
Design of High Speed Machinery	500
Crops for Industrial Use	1,500
Agro-Food Quality	500
Techniques for Sustainable Farming Systems	450
Biological Treatment of Soil and Water	500
Cell Engineering	500
TOTAL	**5,830**

The Council also has its own Collaboration With Industry Scheme (CWIS) which follows LINK principles but operates on a project basis in areas not covered by LINK programmes. Twenty five projects costing AFRC a total of £3.4M at various institutes and universities have been approved to date. This sum has been matched by industry.

In 1992/93 the Council spent over £1M on these LINK and CWIS activities.

***Scott Lawrie**, AFRC Central Office*

Institute income from commercial and other sources



Over half the income comes from industry and associated levy bodies. The balance comes from sources such as ODA, DTI, MAFF Open Contract Fund, Trusts, Charities and the EC.

▲ The world's first calves of pre-determined sex.

World's first calves of pre-determined sex

Research at the Babraham Institute in collaboration with the United States Department of Agriculture and Animal Biotechnology Cambridge (Mastercalf) has led to a technique for separating the X- and Y- carrying sperm of bulls. This has been successfully employed to produce calves of pre-determined sex.

The technique is based upon the fact that sperm carrying the X chromosome, which result in female calves, have about 4% more genetic material (DNA) than the male-determining Y-carrying sperm. The sperm are stained with a fluorescent dye and separated by passage through a laser beam using a specially modified flow cytometer/cell sorter.

A project currently funded at Babraham Institute by Genus Ltd is investigating possible differences in enriched populations of X- and Y- separated bull sperm that might form the basis of other separation procedures.

***David Cran**, Mastercalf*
***Brian Heap**,*
***Nigel Miller**, Babraham Institute*

FTIR for food and other applications

An initial concept investigated at the Institute of Food Research has led to development of a novel, inexpensive and rapid system for on-line analysis of the composition of foods which is now being factory-tested.

The system uses Fourier Transform Infrared Spectroscopy (FTIR) - in this technique the absorption of infra red light by a sample is measured, the frequency of light absorbed indicating the components present in the sample. Initial research focused on the development of a system for capturing FTIR data from food samples and correlating these with compositional information. Conventional probes for FTIR are made of toxic materials. A food-safe probe was developed using a novel sapphire attenuated total reflectance crystal - designed for specific optical geometry. This has been patented and is now licensed to Graseby Specac Ltd.

A fibre optics system for process control, to allow the FTIR to multiplex to a number of sampling points has been designed in collaboration with BTG and is the subject of another patent. Under a LINK project three FTIR systems are now being factory-tested in collaboration with instrument manufacturers and food companies.

As well as applications in quality control, the FTIR probe can be used by retailers for product authentication. Because of its robust and inert nature, it also has potential applications in industries other than food, for example, in the pharmaceutical and petrochemical industries.

▲ Novel sapphire attenuated total reflectance crystal - the key to a new on-line method of measuring the composition of foods.

***Reg Wilson**, Institute of Food Research*

Natural control of slugs

A natural, biological method of slug control using a naturally occurring strain of nematode worm has been developed by the Agricultural Genetics Company in collaboration with scientists at the Institute of Arable Crops Research, Long Ashton Research Station.

The nematode strain was isolated from soil and is now being grown in special fermenters. It burrows into the slug through a tiny pore on the back of the mollusc, where it reproduces and eventually kills it, before moving to another host.

The nematode strain infects and kills a range of slug species, including all the economically important pest species of Europe. It provides an effective method of pest control at temperatures down to 5°C and is specific to molluscs. The effectiveness of this method of control has been successfully demonstrated in initial field trials on winter wheat and lettuce. These trials are now being extended. It is envisaged that a commercial product will be available by 1995/96.

▲ Slugs - the mantle of the slug on the left is swollen due to infection by the nematodes used for biological control.

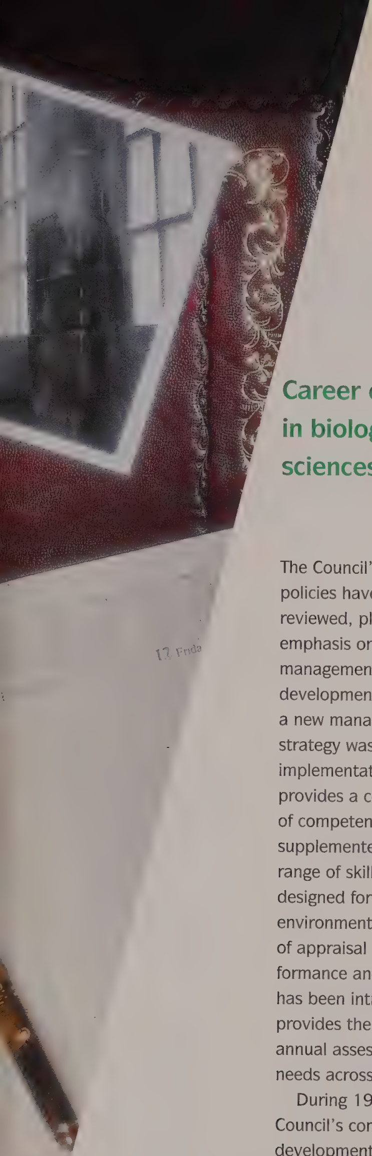
***David Glen**, Institute of Arable Crops Research*

A scientific basis for national policy making

> ***"There are educational and cultural reasons for funding research: research is needed to inform or develop policy...(1.4)***
>
> ***"So pervasive are science and technology nowadays that most Government Departments use them - to a greater or lesser extent - when exercising their policy, regulatory, statutory and procurement responsibilities... (5.1)***
>
> ***"It is also important to ensure that the United Kingdom exploits to the full opportunities to capitalise on overseas research and development and to promote British science and technology abroad..." (6.20)***
>
> *Realising our Potential: A Strategy for Science, Engineering and Technology.*

The Council receives commissions from Government Departments, principally MAFF, that directly relate to policy issues in UK agriculture, food, nutrition and so on. In addition, fundamental research supported through the Science Budget provides a basis for understanding processes such as the spread of animal disease, biology of food-borne pathogens, and plant-environment interactions that are also directly relevant to policy formulation.

As well as information relating directly to the details of research programmes, the Council actively contributes to public debate on a wide range of science policy and related issues. During the year the Council presented evidence to the House of Commons Select Committee on Science and Technology: Inquiry into the Policy and Organisation of the Office of Science and Technology, and made a submission to the consultation process which preceded the White Paper on Science and Technology. The Council provided information to assist OPSS Ministers in answering twenty two Parliamentary Questions and thirteen Ministerial cases.



The resource base

Career development in biological sciences

The Council's human resource policies have been extensively reviewed, placing a new emphasis on performance management and personal development. During the year, a new management training strategy was approved and implementation begun. This provides a common "core" of competence-based training, supplemented by an extensive range of skill-based modules designed for the AFRC environment. A new system of appraisal of personal performance and development has been introduced and provides the basis for an annual assessment of training needs across the Council.

During 1992-93, the Council's commitment to the development of genuine equality of opportunity in employment was carried forward with a new set of policy statements covering all aspects of equal opportunities, linked to a programme of senior management seminars, and to a set of clear objectives for the next five years. The Council has affiliated to Opportunity 2000, a Business in the Community initiative aimed specifically at improving the position of women in employment.

The Council has welcomed the increased levels of flexibility and delegated authority in setting terms and conditions of employment made available by HM Treasury and has begun to work towards taking control of its own pay bargaining in 1994-95.

Details of the Council's human resources are given on page 60.

Bob Price,
AFRC Central Office

Support for university research

The support of research and research training is a major aspect of Council's work. Council seeks to develop and sustain high quality research in universities within its range of interests and encourages links between university researchers and scientists at its own institutes.

Postdoctoral fellowships

In 1989 the Council expanded its Postgraduate Research Training to include a Postdoctoral Fellowship Scheme. The Scheme provides support for a small number of outstanding research workers, to enable them to devote a significant period to independent full time research and scholarship. A fellowship is normally awarded for five years in the first instance and provides a salary for the fellow and a substantial setting-up grant to establish an independent research programme. Currently twenty one postdoctoral scientists are supported under the scheme.

Research awards

The majority of AFRC's research grants are awarded in the responsive mode although an increasing number are currently being awarded under coordinated programmes. Research awards include:

- Linked Research Group Awards which provide funding for work by universities which complements and draws upon experience, skills and experimental facilities in AFRS institutes.
- New Investigator Awards which give an opportunity to less experienced scientists to obtain financial support for research at an early stage in their careers.
- Cooperative Research Grant Awards which encourage the participation of UK industry in joint research projects with universities.

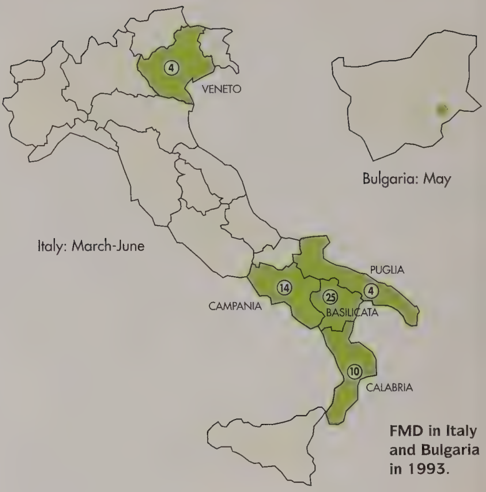
Coordinated programmes bring together a wide range of research groups in AFRC institutes and universities for developing new scientific opportunities. A broad area of research is identified as priority and research groups in AFRC institutes and in universities are invited to submit research proposals. Coordinated programme initiatives are advertised in the scientific press. Research grants within coordinated programmes are usually standard awards and although the general terms and conditions are the same, programme awards can be subject to special conditions specific to each programme. A list of coordinated programmes and their costings appears on page 61, together with details of the Council's grant awards.

Brenda Mortimer,
AFRC Central Office

Systems modelling

The epidemiology and evolution of foot-and-mouth disease

Foot-and-mouth disease (FMD) continues to threaten continental Europe and the United Kingdom. Fifty seven outbreaks have occurred in Italy during the period February to June 1993 and one outbreak in Bulgaria during May. Analyses have shown that the causal viruses originated from the Middle East. How they were introduced into Europe remains a mystery but these examples have highlighted the extensive trade in animals across Europe and the increased risk of rapid disease dissemination since the establishment of the Single Market and cessation of routine vaccination against the disease.



FMD in Italy and Bulgaria in 1993.

Rapid implementation of control measures is essential for eradication of outbreaks of FMD and information about likely spread and evolution of the disease is vital for the planning and management of control procedures. Computer-based models are being developed to aid decision making in the event of an outbreak of FMD. This is part of an EC-supported collaboration with researchers in Denmark, The Netherlands and Italy.

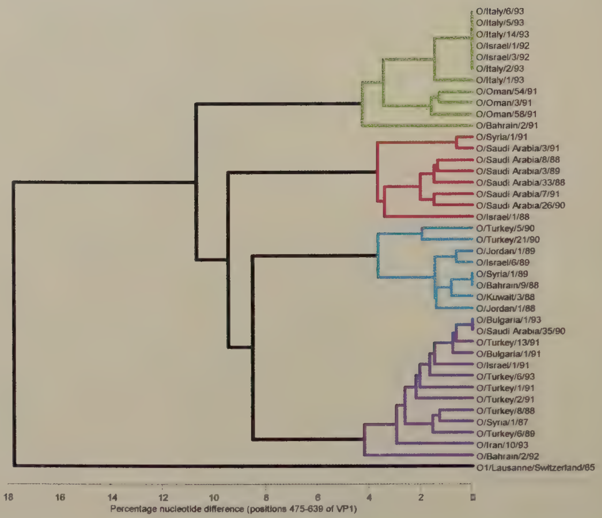
These models will process data generated in outbreaks and predict the risk of disease spreading by direct and indirect contact and on the wind. This will allow identification of the most effective deployment of manpower and most appropriate control measures. An incorporated economic model will estimate the consequences of different control strategies.

There are seven immunologically distinct types of FMD virus and within each serotype many highly variable strains. Variation in a part of the genetic sequences has been analysed in nearly 700 isolates of the virus. This "molecular fingerprinting" revealed related clusters of isolates which are geographically restricted. Characterisation of FMD viruses has been shown to be of practical value in providing information about the origin of outbreaks.

The evolution of FMD virus in countries where the disease is endemic and where epidemics have occurred is being studied in collaboration with the veterinary authorities of several countries including Zimbabwe, Turkey and Saudi Arabia.

Research is focused on understanding what controls variation in FMD virus and how evolutionary rates change. The latter topic is part of a link programme with scientists at the University of Oxford. Biomathematical methods will be used. The application of biomathematics to disease epidemiology modelling offers new and exciting possibilities and was the theme of a research workshop sponsored jointly by the AFRC and SERC at the University of Warwick in May 1993.

Alex Donaldson,
Institute for Animal Health
Mark Woolhouse,
University of Oxford



Genetic relationships between FMD viruses from Italy and Bulgaria in 1993 and the Middle East. ▶

Crop management under environmental change

Environmental change poses challenges and provides opportunities. A better understanding of how plants respond to climatic and other factors will allow agricultural policy makers to plan for likely future scenarios, and aid plant breeders in developing resilient varieties. Studies range from characterisation of molecular and cellular responses in plants to the construction of predictive models of cropping patterns across the UK, under different environmental conditions. Some of this research is supported through MAFF commissions.

The Council's research on biological response to global environmental change includes a new coordinated programme that supports twenty-six projects in eleven universities and three institutes (IACR, IGER, IPSR). Council scientists are also participating in international climate change activities, such as the EC's ENVIRONMENT programme (projects CROPCHANGE and ESPACE) and in core programmes of the Global Change Terrestrial Ecosystems activities of the International Geosphere Biosphere programme. Topics include: effects of elevated carbon dioxide and temperature on plant production, yield and quality, on nutrient partitioning and on interactions between plants and soil microbes together with the effects of temperature on incidence of pests and diseases. Some examples of AFRC supported research are given below.

Modelling how arable crops respond to environmental change

Experimental analysis of the effects of increasing atmospheric carbon dioxide, and of changes in temperature, on arable crop plants is being used to test and improve computer models of crop processes that may be used to predict agronomic and ecological responses to environmental change. The current concentration of carbon dioxide in the atmosphere is 355 cm^3 m^{-3}; it is predicted that this will double by the end of the next century. An accompanying increase of up to 4°C in global temperatures is expected.

A new Climate Change Facility at Rothamsted Experimental Station provides controlled conditions in which plants are grown with different concentrations of carbon dioxide and over a wide range of temperatures following natural diurnal and seasonal changes. Plants are grown with natural daylength and solar radiation supplemented with artificial light to achieve conditions representative of the UK.

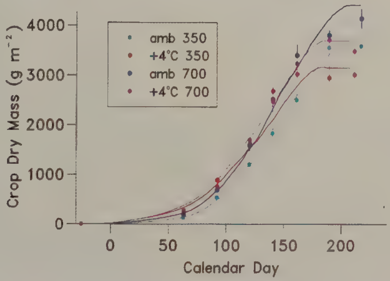
One area of interest is the effect of temperature and carbon dioxide concentration on grain production in winter wheat because of its economic importance. When the effects of increased carbon dioxide and temperature were simulated by the AFRC-WHEAT1 model, the predictions of total dry matter were close to experimental observations (see figure) when the model was given observed leaf area as an input.

Crop modelling must be able to take into account inherent variability in the weather and the non-linear nature of crop responses to environment. For example, water use efficiency changes with absolute supply and small amounts of rainfall are used much more efficiently than larger amounts, affecting leaching and runoff. Extreme conditions such as drought or very hot periods have profound effects, and their frequency will increase if the climate becomes more variable, as has been predicted. Effects of such extreme events will be tested experimentally and by modelling approaches to evaluate the potential damage to agriculture in a changed climate.

The response of sugar beet to conditions of climate change is being examined experimentally and by modelling studies in work supported under the Global Environmental Research Initiative.

David Lawlor,
Institute of Arable Crops Research

The new Climate Change Facility at Rothamsted. ▶



▲ Effects of combinations of carbon dioxide concentrations (350 and 700 cm^3 m^{-3}) in the atmosphere and temperatures (ambient and +4°C) on the dry matter production of winter wheat cv. Mercia grown in 1990/91 season in the simulated field environments. Dry matter production calculated from the total productivity submodel of AFRCWHEAT1.

Warm and wet vs. warm and dry

Predicting how changes in climate would alter the suitability of different crops for regions of England and Wales has been recognised as an important area of scientific research by MAFF. Using mechanistic crop growth models, scientists at the Institute of Grassland and Environmental Research and Environmental Change Unit, Oxford are mapping the possible consequences of climate change.

Most climate research centres predict an increase in the earth's temperature of about 2°C by the year 2070. Variation in patterns of rainfall is also predicted. By combining baseline climate data from 1951-1980 and the needs of the crop for moisture, sunlight and warmth, growth can be determined by the growth model. The accuracy of the results is confirmed by current patterns of cropping. By using this procedure, the consequences of a 2°C rise in UK temperatures accompanied by a 10% increase or decrease in rainfall can be seen in terms of where crops could and could not be grown.

The maps (below) illustrate the implications for forage maize: an option for most of England and Wales if higher temperature is accompanied by higher rainfall but economic production only in the west if rainfall decreases.

In addition to forage and grain maize this procedure covers main crop and early potatoes, grass, spring barley and pears. These results will aid decision making on crop production and marketing in the future.

Alun Davies,
Chris Pollock,
Institute of Grassland and Environmental Research
Martin Parry,
University of Oxford

Cellular clues to hardiness

The ability of grasses and cereals to recover after freezing, i.e. their hardiness, is being investigated to identify the mechanisms involved. Warmer winters would be expected to lessen hardiness, with the result that plants could then become vulnerable to colder spells if the climate remained variable.

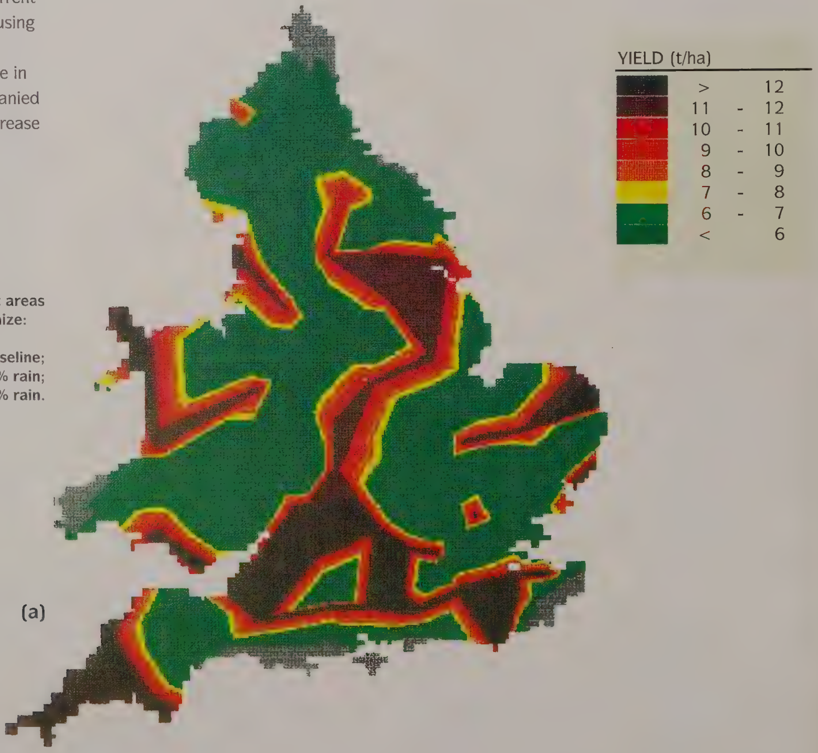
Unhardened seedlings of grasses and oats are killed at about -6°C, but plants that have been hardened can survive, in some particularly resistant varieties to temperatures as low as -15°C. However, in all cases, whether hardened or not, actively-growing tissues of the main apices (growing points) appear to be irreversibly damaged at about -6°C. Resistant plants can grow again from dormant buds whereas in susceptible plants growth may restart but is not sustained. The metabolic basis of these differences between resistant and susceptible plants is being characterised. Cells in the layer below these points are those that are able to stay alive and it seems that in resistant plants they can grow again whereas in susceptible ones growth restarts but then stops. The metabolic differences in resistant and susceptible plants are being characterised.

This is an example of research focused on the effects of environmental change at sensitive parts of plants' annual life cycle where small changes can elicit large responses.

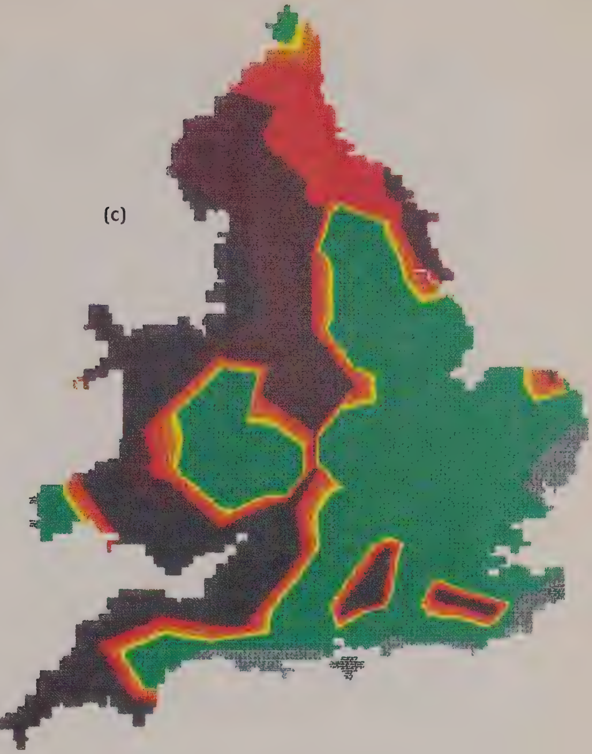
Colin Eagles,
Institute of Grassland and Environmental Research

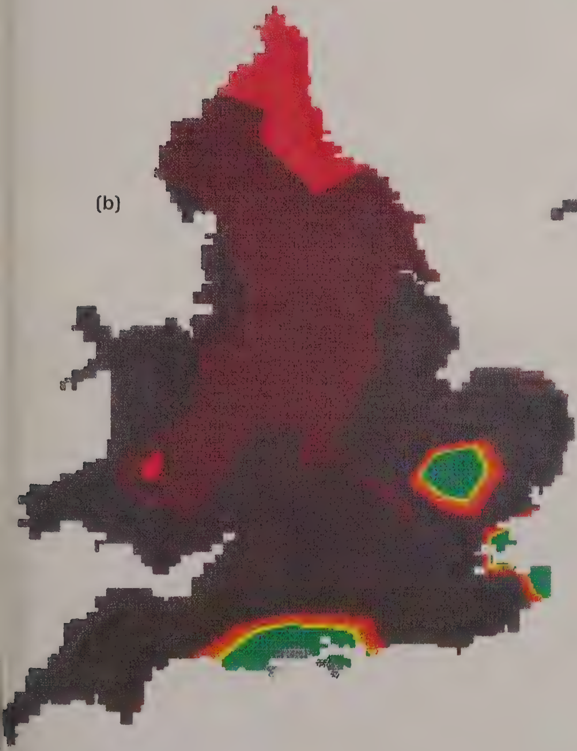
These maps predict areas suitable for forage maize:

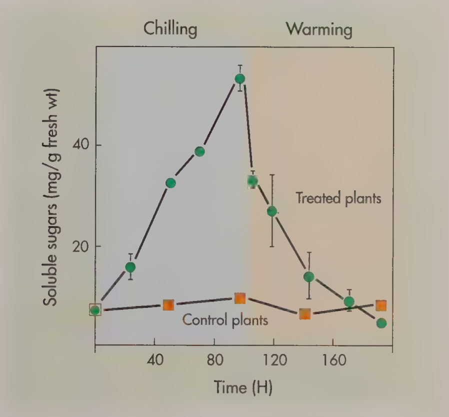
(a) baseline;
(b) + 2°C + 10% rain;
(c) + 2°C - 10% rain.



Frost on grass. ▲







▲ Response of leaf sugars to changes in growth caused by chilling. The roots and growing leaves were chilled to 5°C for 98 hours and then rewarmed. The mature leaves, where photosynthesis occurs, were maintained at 20°C throughout. Reducing demand for sucrose by inhibiting growth leads to rapid accumulation in the leaves. Resumption of growth following rewarming depletes leaf sucrose reserves. Control plants were maintained at 20°C throughout. These data are redrawn from New Phytologist 119 page 502.

Sucrose - a metabolic pivot?

Basic plant physiology suggests that increased levels of atmospheric carbon dioxide would increase sucrose production in grasses and cereals, but that warming would increase utilisation. A collaborative study with the University College of North Wales, Bangor is looking at the effects of environmental factors on the interactions between sucrose metabolism and plant growth.

Chris Pollock,
Institute of Grassland and Environmental Research

Changing patterns of land use

Decision-making in farm management

Techniques of systems analysis and modelling are providing policy makers with ways of predicting impacts of alternative policy decisions on farming, the environment and the rural community. They can also help farmers to make management decisions to optimise profitability.

ARABLE is a farm model designed to determine the annual cropping, labour and machinery which maximise farm profit as affected by set-aside requirements, prices and costs. It can be set to handle farm variables such as soil type and annual rainfall which influence the amount of time that can be spent on different farm operations, and thus to meet the specific requirements of individual farmers. It may be used, for example, to predict the consequences of moving to new crops, or farming more land.

ARABLE is being demonstrated through various channels, including presentations at the industry-supported Morley Research Institute in East Anglia, and through on-farm visits where it is used to tackle real problems and analyse alternatives being considered by farmers. Importantly, the model can indicate options for optimal profitability that may be counter-intuitive. In one example, the option of growing spring rather than winter oilseed rape increased the area of winter barley grown, at the expense of the apparently more profitable winter wheat - the reason being that harvesting time was available in July which was otherwise wasted.

A key feature of the model is the concept of timeliness and rotational penalties. For example, crop yield is reduced if planting is late, but it is generally far too expensive to plant all of the crop at exactly the right time - a balance has to be struck. Rotational penalties are the reduction in yield of one crop following another, for example, wheat after wheat relative to wheat after oilseed rape. They allow the model complete freedom in its choice of crop rotation, while preventing impossible rotations.

Eric Audsley,
Silsoe Research Institute

Organic dairying

It takes at least two years to convert a conventional dairy farm fully to organic standards. Least-cost and environmentally sensitive strategies for managing this conversion period are being identified as part of a MAFF-funded project.

Milk yields, farm costs and environmental benefits are being measured on ten commercial farms that are converting at different rates and at the Institute of Grassland and Environmental Research's Trawsgoed farm. Farm costings and milk quality are being assessed in collaboration with ADAS, and economic modelling is being developed with the University of Wales, Aberystwyth.

The 67 ha all-grass farm at Trawsgoed carried 120 Friesians and used 380 kg N/ha until 1991 when the number of cows was reduced to 80 and application of artificial fertiliser was stopped. Some fields have been slot-seeded with red or white clover, and a new rotation has been introduced. Hedgerows have been planted and their effect on wildlife populations and movement is being monitored. Preliminary results indicate a decline of about 20% in grass production during the first year of conversion.

A new EC project involving collaborators in Ireland, The Netherlands and Germany is addressing potential problems of organic pastures, including the tendency of slurry application to damage clover and encourage weeds, e.g. docks. Mechanical methods of dock control are being investigated. Results suggest that dock roots will not regrow if severed below the crown, and the top will die if buried below 15 cm.

Arthur Hacking,
ADAS
Roger Haggar,
Institute of Grassland and Environmental Research
Peter Midmore,
University of Wales

▲ **The consequences of organic conversion on soil fertility, crop performance, milk yield, animal health and biodiversity are being measured on an AFRC farm and ten commercial farms.**

▲ **Computer models aid decision-making on stocking density and grazing pattern on hill vegetation to optimise productivity and minimise environmental impact.**

Modelling silvopastoral systems

The economic feasibility of growing trees at wide spacing in pasture depends on the levels of tree growth and animal performance that can be achieved. Scientists at the Institute of Grassland and Environmental Research (IGER) are participating in a multi-site experiment, covering a range of environments throughout the UK, to identify the effects of tree species and spacing on timber and animal production. This work is being conducted in collaboration with MAFF, the SOAFD-funded Macaulay Land Use Research Institute (MLURI), the Department of Agriculture for Northern Ireland, the University College of North Wales and the Forestry Commission. From January 1993, collaboration has been extended under a 4 year EC project on "alternative land use with fast-growing trees", with partners in France, Italy, Portugal, The Netherlands and Greece.

Ash, sycamore and hybrid larch have been planted at wide spacing into sheep-grazed pasture at IGER sites at North Wyke in Devon and Bronydd Mawr in Wales. Scientists are particularly concerned with aspects of tree establishment; plantation management; pasture growth and interaction with the trees; livestock production; and ecological impact. From the data, a bio-economic model will be constructed in which yields, product values, and markets will also be considered. This will help farmers' decisions on extensification, as well as providing a basis for policy formulation on socio-economic aspects relating to changes in land use and on options for import substitutions.

William Eason,
Institute of Grassland and
Environmental Research

Management of hill grazing

Computer models are helping land managers to devise grazing strategies that are economically viable and meet objectives for environmental conservation.

Throughout the European Community there is concern about the impact of changing grazing patterns on hill vegetation. For example, in the UK it is estimated that the area of heather moorland has declined by 25% since 1940.

Grazing by both domestic and wild herbivores has a large impact on the botanical composition of semi-natural vegetation. For example, cattle and sheep have different effects on moor mat grass (*Nardus stricta*) - the percentage of *Nardus* cover under sheep grazing is much higher than under cattle grazing. Mixed grazing of cattle and sheep is being explored as an option for maintaining botanical diversity and improving animal performance. Daily liveweight gain in lambs is higher when cattle and sheep graze together, compared with sheep only grazing.

A computer model is being developed that integrates information on climate, rainfall, altitude, vegetation and stocking density. It indicates biomass production and sward heights of different types of vegetation, quantity and quality of diet and grazing times. The model is currently being used by Government Agencies and land managers to help set stocking rates for specific areas of land.

Iain Wright,
SOAFD-funded Macaulay
Land Use Research Institute

The nation's health

Microorganisms causing food-borne diseases

A coordinated programme on the biology of microorganisms causing food-borne diseases was established by the Council in 1992. It brings together researchers in ten universities to complement existing projects and studentships and work at the Institute of Food Research.

The programme includes research into mechanisms of microbial survival and growth, novel approaches for investigating enteropathogens that cannot be cultured, and the effects of food structure on microorganisms in food. It is coordinated by Colin Ratledge of the University of Hull. Some examples are given below.

Stress adaptation in *Listeria monocytogenes*

The food poisoning bacterium *Listeria monocytogenes* is able to tolerate many procedures of conventional food preservation. For example, it can withstand high concentrations of salt - over three times those that can be tolerated by *Escherichia coli* - and it can grow at temperatures as low as 1°C.

Fundamental research is aimed at understanding the physiological responses that allow *L. monocytogenes* to cope with these osmotic and cold stresses, and at identifying the genetic regulation that determines these adaptations.

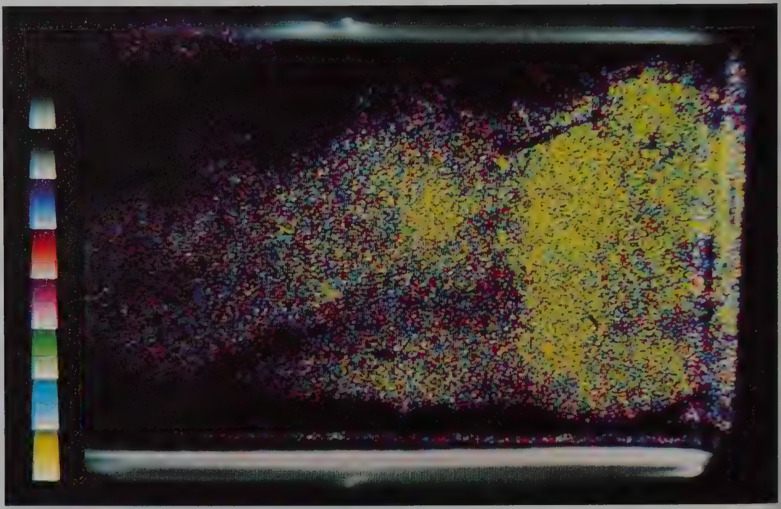
Bacteria protect themselves against osmotic stress by accumulating in the cytoplasm specific solutes (e.g. betaine) that are compatible with enzyme function. The level of the solute in the cytoplasm is determined by the degree of osmotic stress imposed upon the cells and involves very tight regulation of enzyme systems and transport mechanisms. *Listeria monocytogenes* is very salt resistant and is frequently associated with cheeses and pâtés and recent studies have identified a key role for peptides, which constitute a major component of these foods, in protecting this organism from osmotic stress. The integration of betaine accumulation and peptide metabolism in *L. monocytogenes* are being characterised in a programme that integrates genetic and physiological studies through the isolation and analysis of osmotically-sensitive mutants.

Complementary studies are being used to identify the regulatory elements in the genetic material that respond to high salt and to low temperature, and the genes that they control. It is the products of these genes that are involved in the physiological changes seen during adaptation.

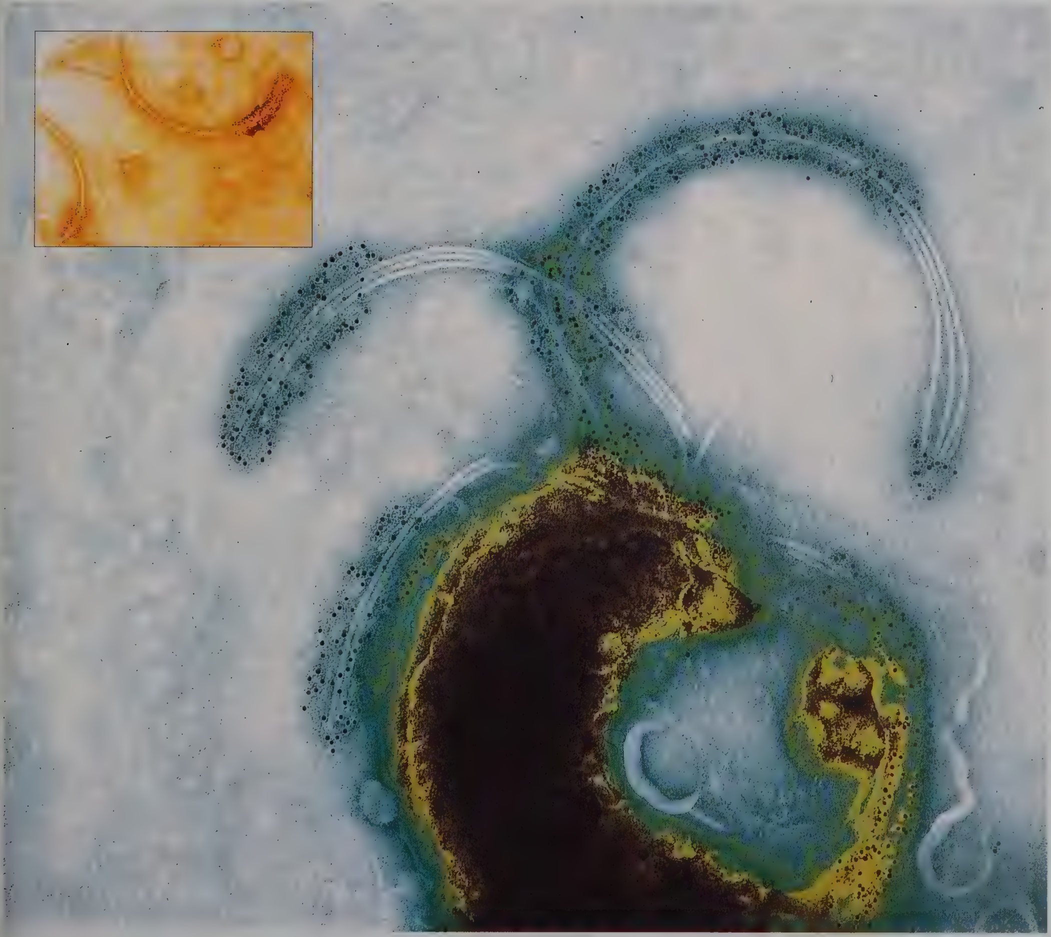
Fragments of the chromosome of *L. monocytogenes* are being tested for their ability to switch on genes (in this case, "marker genes" for bioluminescence) when subjected to osmotic stress. This will allow identification of fragments containing the regulatory elements that respond to high salt.

One approach being used to identify genes that code for the products that effect adaptation is the comparison of the profile of proteins produced by *L. monocytogenes* before and after imposition of salt and cold stresses. The stress-induced proteins are being isolated and characterised so that techniques of molecular biology can be used to work backwards from these protein sequences to identify the genes that coded for them.

***Ian Booth,** University of Aberdeen*
***Gordon Stewart,** University of Nottingham*



Numerous bioluminescent *Listeria monocytogenes* attached to a stainless steel "coupon". This technique is being used to study how bacterial cells attached to a surface are able to resist heat, freezing and biocides. ▶



▲ **A cell of the gastric pathogen *Helicobacter pylori* has been treated with a monoclonal antibody against the flagellar sheath; the antibody is made "visible" for electron microscopy by (its reaction in turn with a second antibody directed against the first and) associated colloidal gold particles which show up as opaque dots.**
Inset: A similar labelling reaction, using an antibody directed against a part of the flagellar shaft.

The biology of bacterial flagella and their role in pathogenesis

Little is known about how the gastrointestinal pathogens *Campylobacter jejuni* and *Helicobacter pylori* cause infection. But both these spiral bacteria possess flagella - thread-like "tails" by which the organisms move - and motility and/or possession of flagella is thought to help bacteria to colonise or adhere to the surface of cells lining the gut, and to invade the cells.

C. jejuni and *H. pylori* are broadly related, and the flagellin proteins that make up their flagella are known to be similar. But the flagella of *H. pylori* are encased in a membrane-like sheath containing specific proteins, whilst those of *C. jejuni* are unsheathed. This means that the two species provide a good comparison for studying the role of flagellins and associated proteins in pathogenicity.

Monoclonal antibodies (Mabs) are being raised against the flagellins of each species and the sheath proteins of *H. pylori*. The extent to which each individual Mab interferes with flagellar function in mobility, cell adhesion and invasion will indicate which parts of which proteins are involved in these processes.

The introduction of site-specific changes in the amino acid sequences of key flagellar proteins will provide even more detailed information about the structural determinants of function.

Charles Penn, *University of Birmingham*
Peter Richardson, *Institute of Food Research*

Cellular and physiological responses to dietary components

A better understanding of the underlying mechanisms by which the body responds to components of diet is important for the development of nutritional policies.

Dietary fats and membrane fluidity

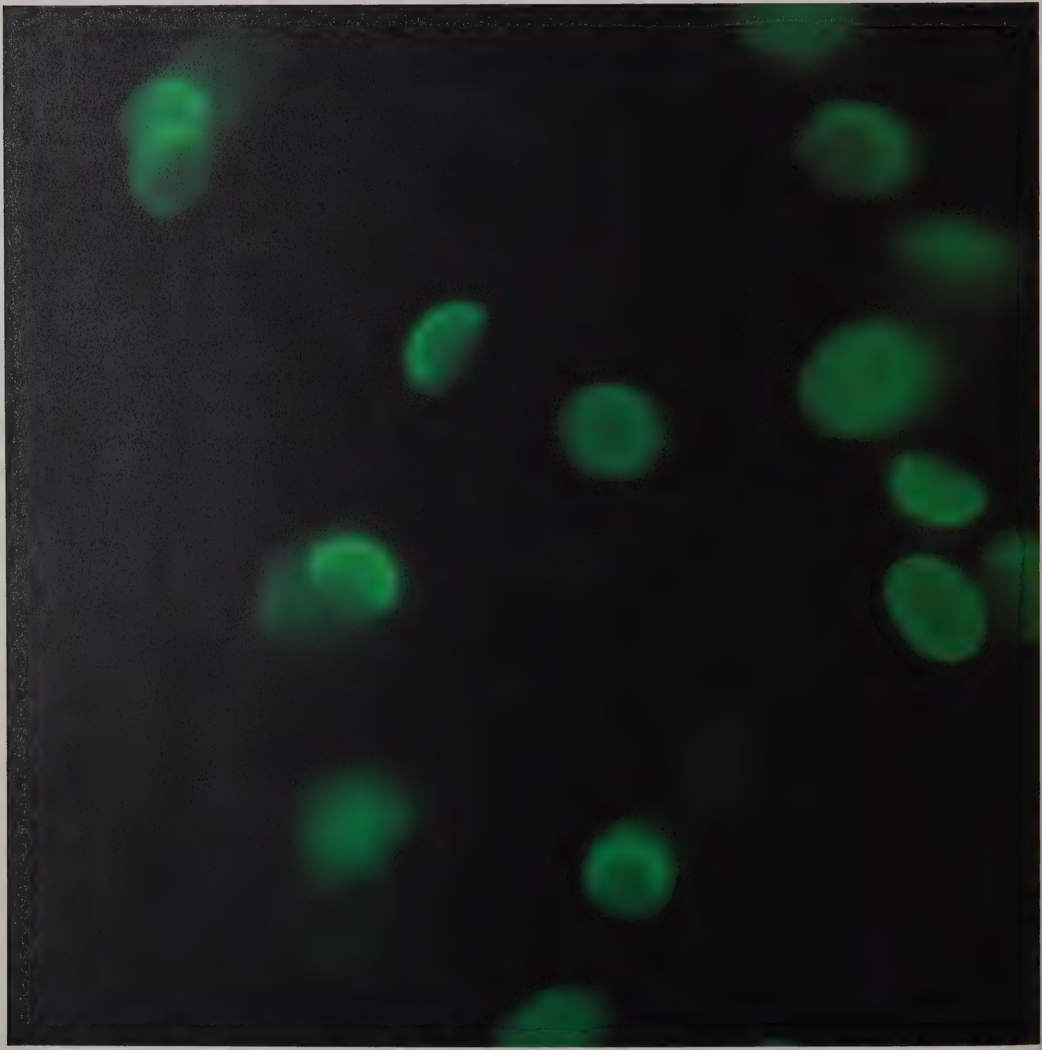
Highly unsaturated dietary fatty acids, such as the n3 fatty acids present at high levels in fish oils, are incorporated into cell membranes. This might increase membrane fluidity and may be beneficial, for example, by aiding peripheral circulation and helping to prevent cardiovascular disorders.

When human volunteers were fed a fish oil supplement, the proportion of n3 fatty acids in the membranes of cells from their cheeks increased. Their red blood cell membranes became more fluid - fluidity is measured by a technique in which the membranes are stained with a fluorescent dye, "bleached" locally by a short laser pulse, and then left to recover. The rate of diffusion of molecules of fluorescent dye into the bleached spot is used to calculate membrane fluidity - the faster the molecules of fluorescent dye diffuse into the bleached spot, the more fluid the membrane.

This research, funded by MAFF, is aimed at examining how such diet-induced changes in membrane fluidity affect important functions of the tissues such as the regulation of the transport of materials in and out of cells, and recognition and response to cell signals such as hormones.

David Clark,
Ian Johnson,
Institute of Food Research

Fluorescence recovery after photobleaching image of red blood cells. ▼



Vitamins and antioxidant activity

Oxidative damage to cells has been linked to development of cancer and vascular disease. For example, the greater risk of heart disease in individuals with a high proportion of low density lipoproteins (LDLs) in their blood is thought to be at least partly caused by cells (macrophages) in the coronary arteries accumulating LDLs that have been damaged by oxidation, enlarging within the arterial wall and eventually blocking the arteries.

Oxidation might damage the macrophages themselves as well as the LDLs. This is being examined by studying the effects of oxidation on membrane function of cells in culture. Of particular interest is the possible role of antioxidant vitamins (including C and E) in protecting cell membranes from damage, and the mechanisms of such protection. One hypothesis being tested is that the vitamins, being long chain unsaturated molecules amenable for attack by oxidants, act as "sacrificial" molecules that are preferentially attacked. The ability of vitamins to act cooperatively, i.e. exert a greater effect in mixtures than the sum of the individual effects, is also being explored.

Paul Dowrick,
Sue Southon,
Institute of Food Research

Metabolic response to dietary glucose

The location in the gut at which nutrients are absorbed is likely to depend on the complexity of the food. For example, glucose from a simple carbohydrate might be absorbed very early in a proximal part of the gut, but that from a complex unhydrolysed carbohydrate might not be absorbed until after fermentation in the colon.

It is not known how differences in the site of absorption might influence the body's response to nutrients, for example, hormonal responses and effects on appetite, satiety and mood change. There might also be effects on the metabolic fate of nutrients, for example, governing whether glucose is broken down or stored as fat or as glycogen.

Computer models simulating sites of digestion/ absorption and their effects on physiological response and metabolism are being developed using human volunteers. Stable isotopes of glucose are used to measure rates of uptake into and clearance from the circulation of glucose from a variety of types of food. This MAFF-funded research is conducted using the residential Human Nutrition Unit at the Institute of Food Research at Norwich.

Geoff Livesey,
Institute of Food Research

Appetite control and fat consumption

Research into the influence of dietary fat on hunger, eating patterns and subsequent fat consumption will aid the design of strategies for improving the nation's diet.

Human appetite is controlled by many psychological, metabolic and neural mechanisms. Patterns of eating are profoundly affected by the satiating effects of foods - the extent to which foods create a feeling of "fullness". Two features can be distinguished: satiation - the process which brings to an end an eating episode; and satiety - the state of inhibition over eating brought about by the consequences of food ingestion.

Dietary fat has only a weak effect on appetite control. A high fat intake has a disproportionately small effect on satiety. For example, when subjects ate a test breakfast containing a concealed supplement of either fat or carbohydrate, the drive to eat at between one and three hours after the meal was significantly reduced in those who had eaten the carbohydrate supplement but not in those who had eaten the fat supplement.

This has two implications. It suggests that if our bodies can detect changes in fat intake at all, any feedback control on appetite is easily overridden. This would help to explain the high incidence of obesity in developed countries such as the UK.

Secondly, it suggests that replacing fats in food by non-absorbable fat substitutes might be achieved without reducing the satiating power of the food. This would offer a way of designing healthier diets without reducing satisfaction to the consumer.

A separate study is identifying and characterising groups in the population with high, medium and low levels of fat intake. Appetite levels, motivation in food choice and eating patterns are being compared in these groups, and correlated with physiological responses such as blood insulin and glucose levels, and rates of release of cholecystokinin - the hormone that triggers release of bile into the intestine in response to the presence of fat.

This information, together with personal and social data will help to identify factors that influence fat intake, and thus suggest strategies for effective food policies and guidelines to effect dietary change in the UK.

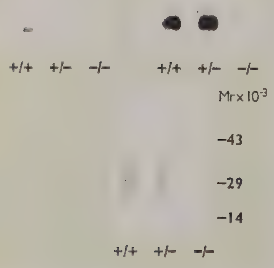
John Blundell,
University of Leeds

Animal health and welfare

Molecular characterisation of scrapie, BSE and related diseases

The biology of in-bred lines of mice that are inherently not susceptible to infection by scrapie is providing a basis for detailed molecular analysis of the factors that influence susceptibility, disease and infectivity in scrapie and in other transmissible spongiform encephalopathies.

The sheep disease scrapie, bovine spongiform encephalopathy (BSE) and the human dementia Creutzfeldt-Jacob disease are examples of a family of neurological degenerative conditions in which the infectious agent is unknown. An abnormal form of the glycoprotein (PrP), a normal component of the membranes of nerve cells, has been implicated in the pathogenesis of these diseases, as has the host immune system. There is now evidence that mice that lack PrP are uninfectable with scrapie, and those with severely impaired immune function, called SCID mice, are not susceptible to scrapie infection via peripheral inoculation.



▲ **Gels showing that "PrP null" mice do not produce the mRNA for PrP or the protein.**

Scrapie has existed for at least two hundred years. About twenty experimental strains have been isolated, but how many occur naturally is unknown. Studies on sheep genetics show that variation in the gene for the PrP protein is associated with altered susceptibility to different strains. For example, one mutation makes sheep susceptible to certain strains of scrapie whereas another mutation is linked to susceptibility to the BSE agent and another different strain of scrapie. Relative resistance to scrapie can be defined, therefore, only in terms of the particular strain. This has important implications for the design of eradication strategies.

Although PrP is clearly involved, there is no simple correlation between levels of abnormal PrP and infectivity; it remains unclear whether PrP is itself the infectious agent or a part of a complex involving other molecules, the combination of which is necessary for pathogenesis and replication of the agent.

A Swiss group and scientists at the Institute for Animal Health have bred mice that lack the PrP gene. These "PrP null" animals appear quite normal, which raises important questions about the role of PrP. The Swiss research has indicated that mice without the PrP gene are not susceptible to scrapie and do not replicate the agent. If this is confirmed at IAH, then step by step comparison will be made of animals that carry genes coding for different parts of PrP. In this way it might be possible to identify parts of the protein associated with replication of the infectious agent, or with PrP aggregation into fibrils or with susceptibility to disease and so on.

In a similar way, mice lacking a functional immune system have been shown to be not susceptible to infection by scrapie introduced by a peripheral route - the supposed route of natural scrapie infection. These individuals provide a "baseline" against which the effects of individual components of the immune system can be tested individually to see which are involved in presenting infectious agent to the nervous system and thereby generating disease.

For the first time, detailed dissection of the cells and molecules involved in scrapie is possible. This will allow a more systematic approach than hitherto to the identification of the processes governing susceptibility and pathogenesis.

Chris Bostock,
Hugh Fraser,
Jean Manson,
Institute for Animal Health

Recombinant PrP for structural studies and diagnostics

Elucidation of the structure of PrP is expected to provide clues about the normal function of the protein and about how alterations to its structure might contribute to pathogenesis. For example, mutations that affect host animal susceptibility to disease could be located in the structure, and how these alter the characteristics of PrP could be determined.

Such structural analyses require relatively large quantities (milligram) of pure protein which are not readily available from animal sources. These are now being produced by recombinant DNA technology. The PrP genes of mice, cattle and sheep have been cloned into bacteria, and the mouse gene has also been cloned into mammalian cell cultures. A Linked Research Group with the University of Oxford has commenced structural investigations of PrP, including work to develop a crystal structure.

Recombinant PrP has also facilitated development of improved antibody probes for use both in experimental analysis of disease and in diagnosis. For example, two monoclonal antibodies have been produced that recognise two different parts of the PrP molecule, only one of which remains after digestion by protease. It is anticipated that these might form the basis of a diagnostic test for BSE. Longer term it might be possible to produce antibodies that recognise only abnormal PrP.

Alan Bennett,
Christopher Birkett,
Chris Bostock,
Robert Somerville,
Institute for Animal Health

Meeting legislation on poultry welfare during transportation

Engineers and physiologists are working in collaboration with a major commercial broiler producer to provide a scientific basis for ensuring the welfare of birds in transit.

Legislation exists to protect poultry in transit and current welfare codes established by MAFF state that birds "should be protected from bad weather and from excessively hot or cold conditions"(*). The Farm Animal Welfare Council has drawn attention to the need for adequate ventilation of vehicles to prevent "adverse conditions during transport". The poultry industry recognises however that, during transport throughout the course of the year, birds can become hypothermic (a reduced body temperature) or hyperthermic (an increased body temperature).

Scientists are working to gain an understanding of the causes and effects of thermal stress. Initial studies have addressed the case of hyperthermia and have focused on two objectives. The first is to derive a simple index of thermal stress - a combination of air temperature and moisture content - which can be used to define an acceptable range of conditions for poultry during transport. The second is to use this knowledge to identify design criteria and produce specifications for ensuring these conditions during transport.

Temperature and relative humidity within transport containers have been measured at various locations on a vehicle. These data demonstrate the heterogeneity of conditions throughout the vehicle and have shown that adverse conditions can develop which seriously compromise the ability of the birds to thermoregulate. Prolonged exposure to such conditions can result in mortality.

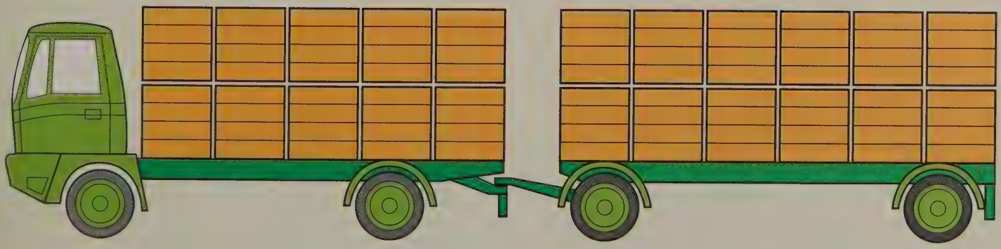
A parallel study is investigating the air flow around and within transport vehicles. Pressure measurements and flow visualisation techniques on full scale vehicles are complemented by wind tunnel measurements on a 1/8th scale model. The results show that ventilation in some parts of the vehicle is insufficient to remove heat generated by the birds, a direct consequence of which is the formation of adverse micro-environments.

This multi-disciplinary approach to the welfare of poultry during road transportation will define by scientific means acceptable thermal limits for poultry during transportation and provide essential specifications and designs for future poultry transport vehicles.

(*) The welfare of poultry (transport) order. Statutory Instrument Number 851. (1988).

Chris Baker,
University of Nottingham
Peter Kettlewell,
Silsoe Research Institute
Malcolm Mitchell,
Roslin Institute

Diagram of a poultry transport vehicle. ▼



European dimension

European partnerships

The Council has a strong programme of European activities including participation in EC programmes, bilateral collaborations with Community states and participation in the European Science Foundation. Examples are given on these pages and elsewhere in this Report, for example on pages *10, 21, 22, 30* and *35*.

During 1992/93 effort has been made in support of proposals for the third EC R & D Framework Programme, and in negotiations on the fourth. The Council has successfully bid for contracts, and in several cases AFRC scientists are project coordinators, in the following lines of the third Framework Programme:

Agriculture and Agro-industry (IACR, IFR, IGER, SRI)

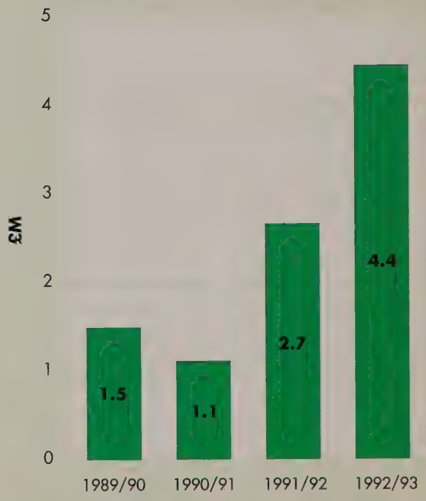
Biotechnology (Babraham, IACR, IAH, IFR, IPSR, Roslin)

Environment (IACR, IGER)

Life Sciences and Technologies for Developing Countries (IFR)

Human Capital and Mobility (IPSR)

Biomedical and Health Research (Centre for Genome Research)



AFRC Income from the EC since 1989/90

UKRHEEO

The Council exercises administrative responsibility for the UK Research and Higher Education European Office in Brussels, and for the steering committee for that Office. The Office services over eighty universities and other higher education institutions in the UK as well as the UK Research Councils and the British Council.

European Science Foundation

AFRC belongs to the ESF - a non-governmental organisation established in 1974 to advance European cooperation in basic science. The Council is represented at the Annual General Assembly and at meetings of the European Science Research Council - an ESF committee covering the natural sciences.

In recent years the AFRC has increased its involvement with ESF. For example, Council scientists have joined programmes on Biological Macromolecules, Developmental Biology, and the Biophysics of Photosynthesis. We are developing proposals for new ESF networks. One is on "long range gene mapping" led by the Institute of Plant Science Research.

Bilateral collaborations

The Council continues to strengthen its links within Europe, through formal, but flexible and non-constraining Memoranda of Understanding with the French Institut National de la Recherche Agronomique (INRA), and the Netherlands Dienst Landbouwkundig Onderzoek (DLO). Meetings to discuss the scientific collaborations going on under each were held in December 1992 and January 1993, respectively. Bilateral cooperation with other countries was further encouraged with the help of the British Council offices in Spain, Italy and Portugal, and through the Council's International Scientific Interchange Scheme (ISIS), which provided funds for AFRC scientists and grantholders to travel overseas.

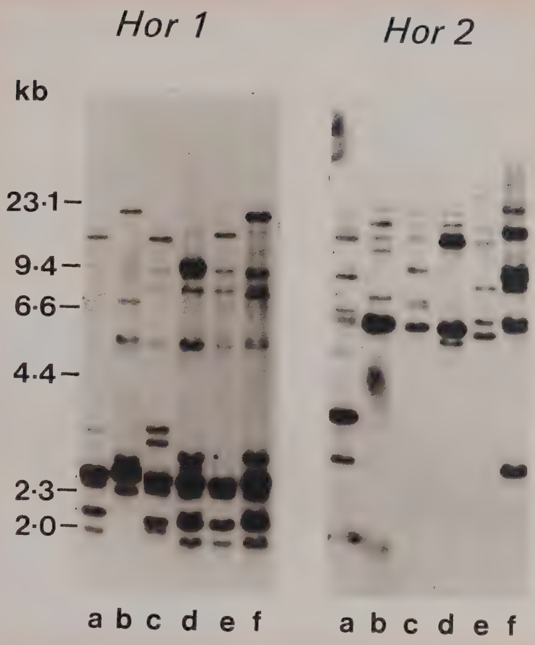
Molecular screening of biodiversity

We need to conserve natural genetic variation on the planet not only for ethical and aesthetic reasons, but also, to use natural biological systems even more efficiently in agriculture, food and other industries. More needs to be known about how to screen rapidly the natural variation that exists and how it can be conserved and accessed for industrial purposes.

Thirty five European laboratories including some private sector companies are collaborating to develop molecular techniques for screening genetic diversity in natural and cultivated populations of plants and animals and in gene banks, herbarium and museum collections. This includes developing techniques of genetic fingerprinting to discriminate between plants that previously appeared identical; identifying "universal" probes that will work on a broad range of species and genera; and scaling down procedures so that tiny amounts of tissue can be utilised.

This 5.5M ECU project, part of the EC Biotechnology programme, is coordinated from the Long Ashton Research Station of the Institute of Arable Crops Research. It brings together expertise in DNA chemistry, molecular genetics, population biology, taxonomy, animal and plant breeding, biomathematics and instrumentation. A principal goal is the development of techniques that can be used across widely differing groups of plants and animals and for large sample sizes. Strategies are also being devised to identify screening methods particularly suitable for accessions and gene banks, or for assessing genetic diversity in natural populations, or for screening for agronomically important variation such as disease resistance and stress tolerance.

Angela Karp,
Institute of Arable Crops Research



▲ Screening genetic variation in natural populations, in gene banks, and in living, herbarium and museum collections, is essential in developing conservation strategies for biodiversity. DNA probes give characteristic "fingerprints"; here six barley cultivars are distinguished using DNA probes for two seed storage protein genes (*Hor 1* and *Hor 2*).

Devolved model for new EC initiative on plant molecular genetics

The John Innes Institute, together with the German Max Planck Institut fur Zuchtungsforschung, is coordinating a new 24M ECU project on Plant Molecular Genetics for an Environmentally Compatible Agriculture. The two institutes are forming a European Economic Interest Grouping (EEIG) to manage the project which involves 117 research groups from 11 Member States.

The main research areas are:

- plant development
- plant growth factors and gene regulation
- nitrogen utilisation efficiency
- adaptive responses to abiotic stress
- synthesis, partitioning and mobilisation of storage products

Particular emphasis is laid on the development of molecular genetic techniques that provide new options for crop improvement and for minimising environmental impact. What makes this project unique is that it is the EC's first pilot project to test the concept of devolved managerial responsibility in which the EEIG enables scientists to take a leading role in managing an EC-wide project. This includes responsibility for project management as well as organisation of scientific meetings and training needs.

▲ Visiting scientists participate in a research project at the John Innes Centre.

In addition, the project is aimed at securing "added value" by integrating laboratories in different research areas around specific objectives, and at linking scientific researchers with agricultural and bio-industrial activities.

Andy Beadle, *John Innes Centre*

Computer modelling aids nitrogen management

In 1980 the EC Directive on the Quality of Water Intended for Human Consumption, which sets a maximum limit of 50 mg nitrate per litre in drinking water, was adopted by member states because of concern about possible links between nitrate in potable waters and health risks. In 1991 the EC Nitrate Directive, scheduled for full implementation by 1999, was agreed. Member states are required to set up nitrate vulnerable zones, monitor nitrate levels in potable water and any waters where there is a risk of eutrophication (nutrient enrichment and long term effects on flora and fauna) and to establish a Code of Good Agricultural Practice.

Additional nitrate or phosphate in surface waters can lead to excessive growth of algae. When the algae die, and are decomposed by bacteria, oxygen in water is depleted leading to the death of fish. Research is aimed at improving the management of plant nutrients so that efficient crop production is maintained in ways that are cost-effective and environmentally sustainable. One objective of this research is to provide advice to the agricultural community on how nitrogen inputs may be matched more closely to crop requirements - to minimise input costs, reduce losses and allow compliance with the EC Directive.

The Council supports a large and diverse programme of research into many aspects of nutrient cycling. This is funded principally through OST and MAFF. Major themes include the basic processes of nutrient assimilation by plants and its control under different environmental conditions, the chemistry and molecular genetics of nitrogen fixation by microorganisms and the nature of symbiosis with leguminous plants, chemical transformations of nitrogen by microbiological and other processes in the soil and the management of agricultural systems to minimise nitrate leaching from soil, denitrification and ammonia volatilisation.

Experimental data are being used to help construct and validate predictive computer models that simulate nitrogen flow. These not only provide a way of testing theories about nitrogen transformations and cycling in soils, they can also aid nitrogen management, by helping to avoid excessive applications of nitrogen in fertilisers and manures.

Models that predict leaching of nitrate under different conditions assist planners and policy makers who need to know how changes in farm practices and land use will affect nitrate levels in groundwaters and rivers.

"N-CYCLE" is a model that describes average annual fluxes of nitrogen in grazed grassland, according to fertiliser input, soil type, drainage, sward age and previous management and climate. It has recently been extended to allow prediction for whole grassland catchments. In tests, model predictions for the nitrate loading of a number of rivers in grassland catchments corresponded well with recorded levels.

At IACR a suite of nitrogen cycle models are being developed which track the fate of nitrogen coming from both fertiliser and from soil organic matter as it moves through the crop and soil. One version is designed to give farmers more precise advice on the quantity of nitrogen fertiliser to apply to crops in specific situations. By taking account of the supply of nitrogen from the soil, or organic manures, fertiliser can be better matched to crop requirements. This will decrease the risk of excessive nitrate accumulating in soil and later being leached to aquifers. Another version, SUNDIAL (Simulation of Nitrogen Dynamics in Arable Land) is a management tool for use in Nitrate Sensitive Areas.

Interaction between IGER and IACR is aiming to link grassland and arable N models in order to describe better the nitrogen flows in mixed farming systems.

▲ Computer models help us to understand the complex N cycle and predict flow under different cropping and environmental conditions. This allows N inputs to be matched to crop requirements thus minimising costs as well as losses to the environment.

Steve Jarvis,
Institute of Grassland and Environmental Research
David Powlson,
Institute of Arable Crops Research

International dimension

Characterising and controlling a devastating new strain of whitefly

A new strain of tropical whitefly that exhibits increased resistance to certain pesticides, and has the potential to adapt to over 500 species of plants and to transmit at least 60 different plant viruses, is threatening crops worldwide. Research into the molecular recognition processes involved in the interactions between the insect, the virus and the host plant is aiming to aid the development of effective control strategies against insect-transmitted viruses.

In the past, the tobacco, cotton or sweetpotato whitefly, *Bemisia tabaci*, has been only a sporadic pest to certain crop species throughout the tropical and subtropical regions of the world. However, a new strain, or possible species, capable of colonising and transmitting viruses to a wide range of plant species, has recently been identified. This new strain, known as the "B" type, is a far more serious pest to worldwide agriculture than the original strains. It exhibits a high resistance to organophosphate and carbamate based pesticides, increased fertility and an ability to induce phytotoxic responses in certain plant species such as squash and tomato. Morphologically, the "B" type cannot be distinguished from the less harmful strains, but there is a characteristic and distinct difference found by non-specific esterase analysis. This "B" type has been responsible for some of the most devastating infestations, causing over $500M damage to the USA's cotton and vegetable harvests of 1991, and decimating melon crops in the Yemen.

Among the plant species hosting "B" type whiteflies are certain ornamentals such as poinsettias. The worldwide trade in these plants is providing a route by which the whitefly is reaching glasshouse crops in northern Europe and sporadically infesting ornamentals in UK glasshouses.

Concern is being shown by MAFF and growers alike in the appearance of *Bemisia tabaci* in the north European glasshouse industry, mainly because of its ability to vector many potentially crop-destroying plant viruses, particularly geminiviruses (so-called because of their twinned particle morphology). Whitefly-transmitted geminiviruses, for instance, are presently causing losses to cassava crops in Africa, beans and fibre crops throughout North, Central and South America and tomato crops throughout Asia, the Middle East and areas of southern Europe. Experiments have shown that *B. tabaci* populations can acquire and transmit geminiviruses irrespective of their global origins. The ability of "B" type *B. tabaci* to adapt to many more plant species than previous strains increases the possibility of these viruses infecting new crop species as the insect spreads around the world.

◀ A "B" type tobacco whitefly hatches from its larval scale. As well as causing phytotoxic responses to certain plant species that its larvae feed on, it can transmit up to 60 plant viruses, and adapt to more than 500 plant species.

Research is in progress to identify the amino acid sequences in the coat proteins of geminiviruses which facilitate their interaction with a receptor protein within the specific insect vector, enabling acquisition and transmission of the virus. One approach is to compare the coat proteins of geminiviruses no longer transmissible by their insect vector, to those which are transmissible, and identify the sequences responsible for specific insect recognition. Methods of blocking this recognition process could then be investigated.

The development of transgenic plants capable of impeding virus replication is also being pursued.

Ian Bedford,
Peter Markham,
Marion Pinner,
John Innes Centre

Biological control

The use of wasps that parasitise whiteflies as a biological control against *Bemisia tabaci*, pesticide resistance studies and the development of management strategies for integrated chemical and biological control are being pursued at the Institute of Arable Crops Research and at Horticulture Research International.

International partnerships

Other developed countries

The Council is continuing to strengthen its links with leading laboratories in developed countries outside the EC. Particular emphasis is placed on strengthening links with Australia, New Zealand, Canada, Japan and the USA.

Council scientists have continued to lead a joint Research Council programme of exchanges and visits between UK and Australia and New Zealand in support of biotechnology research. Eleven awards were made in 1992/93. The priority areas for collaboration are: membrane transport; mammalian reproductive biology; targeted insertion and deletion of genes, and gene regulation in plants and viruses; transgenic animals; mapping complex genomes; and molecular resistance to disease.

High level meetings with research organisations from Japan have identified several areas of potential collaboration. These include "farming as an engineering process" and genome mapping of plants and animals.

The Council continues to play an active role in the Tetrapartite Meetings - annual meetings of research managers in the UK, USA, France and Canada to discuss research policy and management issues of mutual interest. The 1992 meeting took place in Antibes; the 1993 meeting is being hosted in Edinburgh. Areas under discussion include: biodiversity, food safety, non-food crops and non-food uses, implications for agriculture of health education and dietary change, and biotechnology ethics and risks.

Eastern Europe and the former Soviet Union

The Council's main links with these countries are through science-led collaborations between individual scientists. To foster these links, Central Office established a small interchange system in 1990 to support visits to and from Eastern Europe.

▲ **Brian Jamieson (left) Director of Administration with (left to right) Eram Derejian, BEC Ltd, Scott Lawrie of AFRC and Geogri Tanev, Bulgarian Minister of Agriculture, during a meeting to discuss future strategies for agricultural research development and extension in Bulgaria.**

In 1992/93 over fifty such visits took place supported by this fund at a cost of £51K. There were 35 visits by UK researchers (3 to Romania, 9 to Russia, 7 to Poland, 6 to Hungary, 7 to Czechoslovakia, 1 to Bulgaria, 2 to other parts of the former Soviet Union). Sixteen visits were made by East European researchers to the UK (4 from Russia, 3 from Poland, 3 from Hungary, 1 from Czechoslovakia, 5 from other parts of the former Soviet Union).

EC contract on technical assistance to Bulgaria

Against international competition, the Council has been awarded an EC contract worth £1.5M to provide technical assistance for the reform of the Bulgarian Government's agricultural research, development and extension programme. This award was made under the Community's PHARE (Assistance for Economic Restructuring in Poland and Hungary) programme which supports assistance for economic restructuring in Eastern Europe. Work on the fifteen month contract commenced in September 1992.

The Council has established a local office in Sofia housing a core team of consultants supported by short term technical experts in particular disciplines. The prime task is to review the research programme and to make recommendations for its future direction. In addition the team will perform a physical audit of the R&D facilities within Bulgaria, complete a cost/benefits analysis of research and extension activities and identify training needs in both technologies and management.

Developing countries

The Council has analysed how its strengths in generic technologies of potential benefit to agriculture and food production in developing countries may best be exploited through partnerships for technology transfer. A new publication outlining AFRC's research programmes and commitment to greater links in research and research training is being launched in October 1993.

Rothamsted International

The Council is supporting the establishment of Rothamsted International. This is a new initiative that builds upon the expertise at Rothamsted Experimental Station to advance agricultural sustainability in the UK and worldwide.

The objectives are:

- to foster international cooperation in crop and environmental research;
- to provide the opportunity for scientists from other countries to share their expertise within an advanced multidisciplinary research environment;
- to provide developing nations with technologies and expertise to address problems of agricultural intensification.

ISAAA

The Eurocenter of the International Service for Acquisition of Agri-biotech Applications (ISAAA) has been established at the John Innes Centre in Norwich. ISAAA is dedicated to the transfer of agricultural biotechnology to developing countries.

ISAAA matches the needs of developing countries to environmentally sound and safe technologies, identifies partners from industry, the scientific community and developing countries who may work together on specific projects, and locates sources of funding for these projects.

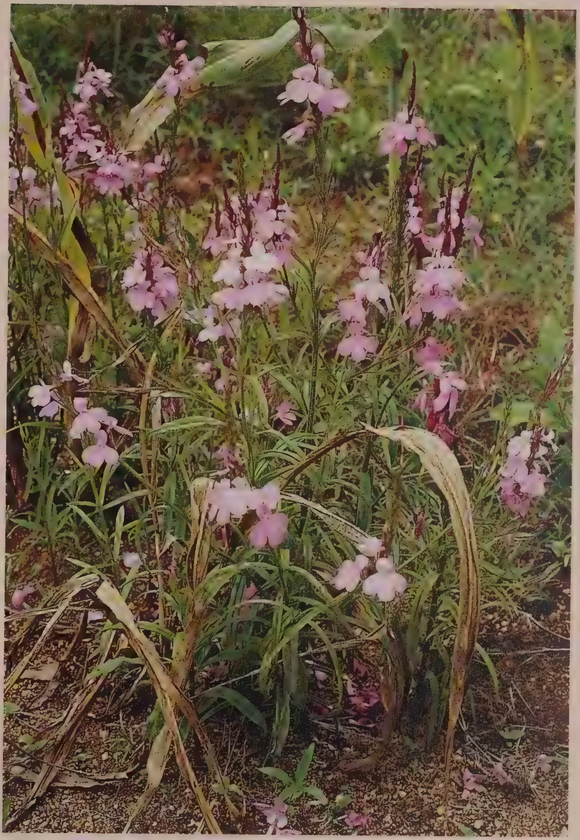
Weed resistance in tropical cereals and cowpeas

Weeds of the genus *Striga* cause considerable damage to cereal and cowpea crops, especially in sub-saharan Africa. Natural sources of resistance in cowpeas have been identified by *in vitro* studies at the Long Ashton Research Station of the Institute of Arable Crops Research. This has led to the breeding of *Striga*-resistant cowpeas at the International Institute of Tropical Agriculture in Nigeria; resistant cultivars should be available to farmers within a few years.

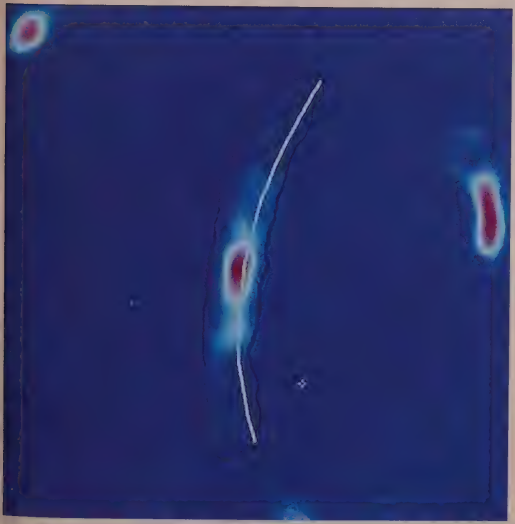
Similar investigations are being undertaken to seek equally effective sources of resistance in maize, millet, sorghum and rice.

This research is funded by the Overseas Development Administration, through the Natural Resources Institute. Under the ODA policy of strengthening national programmes, Long Ashton Research Station has been contracted to provide technical advice and training on weed management and to establish links with the Kenya Agricultural Research Institute, and more generally, by NRI, to provide technical support and management for tropical weed science.

John Terry, *Institute of Arable Crops Research*



Striga hermonthica **parasitising sorghum in Tanzania.** ▶



▲ **A false-colour image of *Brassica napus* chromosomes produced by the image analysis system during image-processing for chromosome identification.**

UK - Japanese collaboration to identify individual *Brassica* chromosomes

Scientists at the John Innes Centre are collaborating with researchers at Hokuriku National Agricultural Experiment Station in Japan to develop technologies that will facilitate genetic improvement in Brassicas.

This collaboration has been funded, in part, by the Japanese Government's STA programme, the Royal Society and the British Council. Previously it has been impossible to identify individual *Brassica* chromosomes because of their small size and uniform appearance but this project has shown that a computer-based chromosome image analysis system, developed in Japan, can be used to characterise individual *Brassica* chromosomes, including those of *B. napus* (oilseed rape). This enables the karyotype (the number and type of chromosomes in a plant) to be determined.

This novel system for chromosome recognition will facilitate the analysis of hybrids and of agronomically important quantitative traits - traits governed by the concerted action of several genes located on different chromosomes. It will also assist in the development of genetic maps and the isolation and cloning of particular chromosome fragments.

Ray Mathias, *John Innes Centre*

The genes for "green"

The genetic programming that controls ageing in leaves is providing clues about how plants that *stay-green* could increase crop value, both in the UK and the semi-tropics.

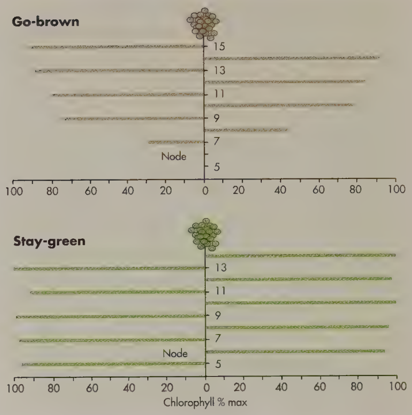
All green leaves are not the same. Some lines of crops such as soybean, maize, sorghum and forage grasses retain their green colour much longer than usual. But for farmers to take full advantage of this they need to know precisely what is happening in the leaves.

Growth, maturation and senescence in leaves are pictured as being under the control of as many as five different classes of gene that operate sequentially as the leaves age. The last two sets seem to govern detection of a signal to start senescence, and senescence itself, respectively. Abnormality in these senescence genes causes the plant to *stay-green*. However, research has shown that superficially similar *stay-greens* differ greatly in metabolism and genetic make-up. It is insufficient for farmers simply to select *stay-greens* by eye. Potential disadvantages as well as benefits must be considered in crop management and breeding programmes.

Normally, loss of green colouration (chlorophyll) directly reflects cessation of photosynthesis. In some *stay-greens* both processes are simply delayed; in others they occur at the normal time, but more slowly than usual. But in others, known as type C's, chlorophyll is retained despite loss of photosynthetic activity. These leaves are effectively "green corpses". They illustrate the importance of characterising *stay-greens* and targeting their uses. Type C's may have enhanced nutritional status because they retain more protein and lipid in the leaves; they may also retain more water, providing juicier forage for animals. But by locking away nutrients in their leaves, type C's seem less able to cope with nutrient stress, suggesting they perform poorly when nutrient supply is restricted, and of course their leaves are not photosynthesising.

A new ODA-supported programme on sorghum *stay-greens* is part of an effort to characterise the genes and gene products controlling leaf senescence. Using molecular diagnostic techniques to screen *stay-greens*, and breeding trials, the senescence genes are being identified. Researchers are close to cloning a putative type C gene from other species. This should allow better exploitation of *stay-greens*, not just in sorghum but in a range of crops. Benefits may be optimised and the disadvantages minimised thereby, not only to improve crop performance but also in amenity and ornamental plants, and in design of "green sponges" to mop up natural pollutants such as excess nitrogen and phosphorus.

Howard Thomas,
Institute of Grassland and Environmental Research



▲ **Sequential senescence during grain formation in sorghum revealed as loss of chlorophyll from the lower leaves of a *go-brown* variety. By contrast, leaves of a *stay-green* variety retain virtually all of their pigment at the same stage.**

▼ **Greenhouse-grown *stay-green* (left) and *go-brown* (right) sorghum.**

Vaccines against tropical Theileriosis

Theileriosis, a tick-borne disease of cattle, is a major obstacle to livestock improvement in many developing countries. It causes serious losses, particularly in imported breeds.

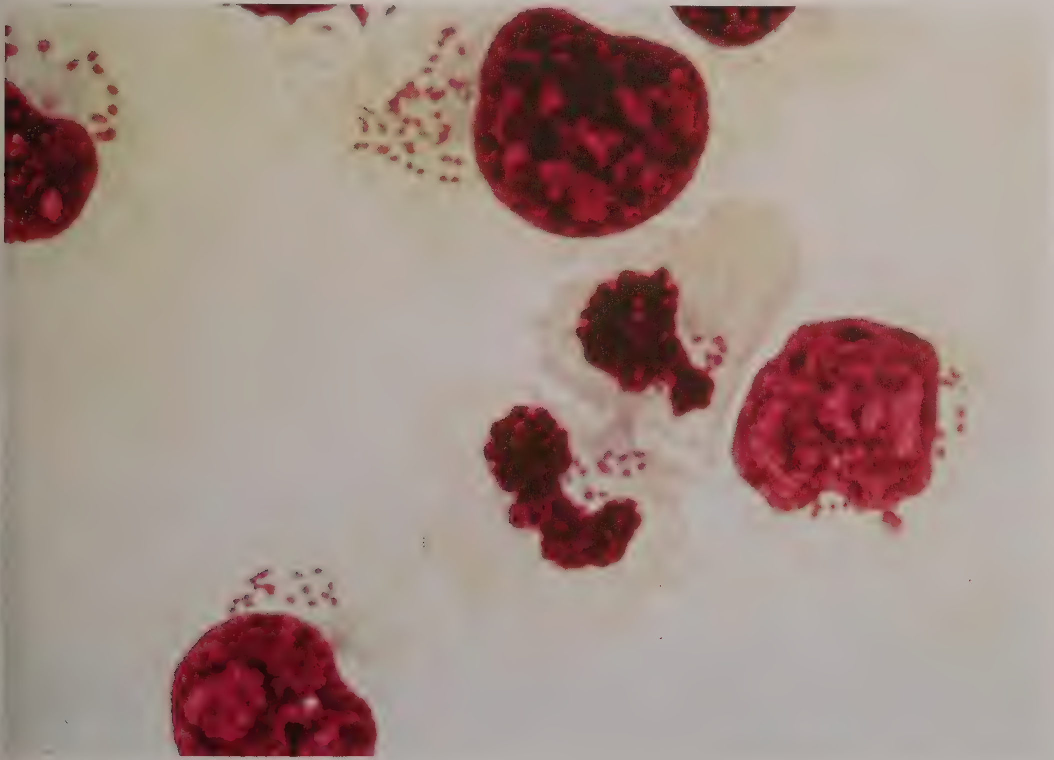
Theileriosis poses enormous scientific challenges and opportunities. It is caused by a protozoan parasite, *Theileria annulata*, which colonises cells of the immune system and causes them to proliferate. The major targets for colonisation by *T. annulata* are the macrophages of the immune system that present foreign antigen to helper T cells. By associating with the cell's apparatus for division, the parasite is able to divide synchronously with its host cell and remain inside the cell.

Research is aimed at developing both conventional and synthetic vaccines to protect cattle against Theileriosis. A major component of the work is attempting to understand how immunity is generated. Currently only live parasite protects. Findings from Theileriosis research might help the efforts to produce a vaccine against malaria.

The epidemiology of the disease and the effect of vaccination on this are being studied in Morocco, in collaboration with the Institute Agronomique et Vétérinaire Hassan ii under EC and ODA funding, a country where losses to Theileriosis are estimated at an equivalent of £7M each year. Clinical disease is seen only in imported and crossbred cattle - not indigenous breeds. Furthermore even in the improved breeds only about 50% of those infected become clinically ill. Thus there is strong circumstantial evidence that genetic resistance exists; experiments are underway to understand the mechanism of inherent resistance. Conventional vaccines are being developed. Cell lines infected with *T. annulata* have been attenuated and tested as vaccines. In one study at a government ranch in Tizitine, 1,500 cattle have been successfully immunised in this way. A field trial of the vaccine in an area of small dairy farmers is currently underway. The new vaccine, which uses a very much lower cell dose than attempted elsewhere, protects for at least one season and remains active for a week without the need for liquid nitrogen storage.

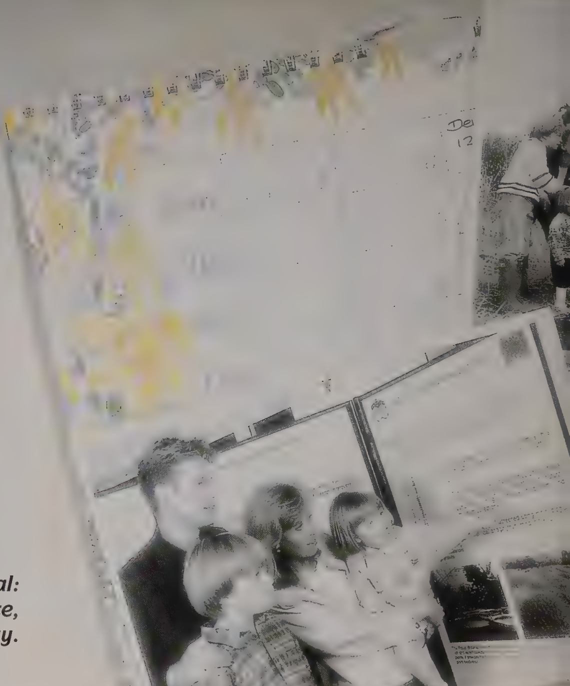
Research is continuing to understand how immunity is generated, commercialise the vaccine and develop predictive markers for resistance so that exporters can be advised which cattle are most likely to survive in Theileriosis areas.

Roger Spooner,
Roslin Institute



Infected lymphoblasts dividing. The DNA of the parasite *T. annulata* divides with the nuclei of the host cell. ▲

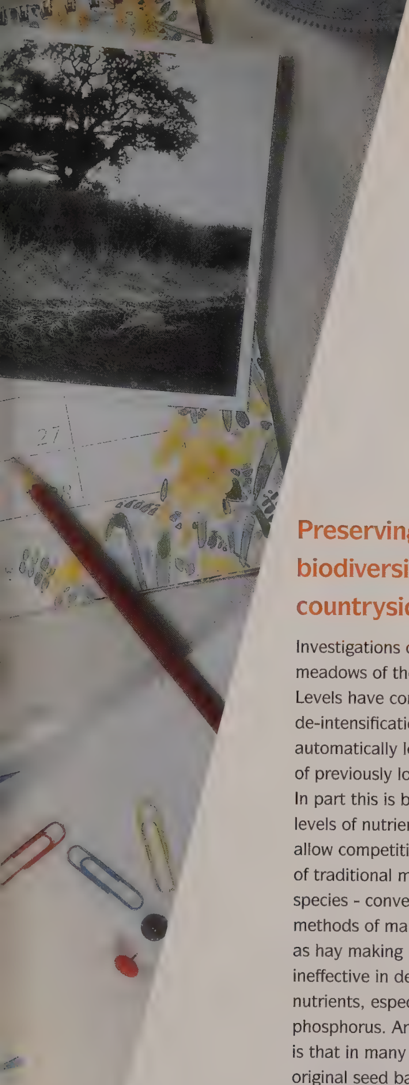
Public issues in the biosciences



> **"...There is also a broader social and economic need to raise the general public's level of understanding and awareness of scientific and technological issues and of the role of science, technology and engineering in the economy..." (7.32)**
>
> *Realising our Potential: A Strategy for Science, Engineering and Technology.*

The Council actively promotes its work through the media and through public exhibitions and publications. In addition, it works closely with other bodies to communicate with specific interest groups, for example, with several organisations that provide resources to science teachers in schools.

Many areas of the Council's work directly address public concerns, for example, about environmental impacts of intensive agriculture, genetic engineering and animal welfare. The Council is expanding its efforts to increase general awareness and understanding of the issues involved by providing objective information to inform public debate.



Social aspects of biology in practice

There is public concern about the loss of native flora and fauna under intensive agricultural management. Several of the Council's research programmes address this issue, and in particular the identification of cost-effective methods for re-establishing species diversity in the countryside. Some of this research is funded by MAFF, DoE and English Nature.

Preserving biodiversity in the countryside

Investigations on the hay meadows of the Somerset Levels have confirmed that de-intensification does not automatically lead to a return of previously lost wild species. In part this is because residual levels of nutrients in the soil allow competitive suppression of traditional meadowland species - conventional methods of management such as hay making have proved ineffective in depleting residual nutrients, especially phosphorus. Another factor is that in many cases the original seed bank has been buried and lost.

A collaborative EC programme with researchers in Belgium, The Netherlands and Spain is aimed at identifying optimum soil conditions for the reconstruction of species-rich communities in extensively farmed grassland.

In another approach, experimental plots are being used to study how native species interact with different types of perennial ryegrass. Plots have been re-seeded with thirteen herbaceous species, including yarrow, oxeye daisy, meadow buttercup and cowslip and subjected to different regimes of cutting. The amenity grass Majestic is conducive to establishment of a herb-rich sward, but longer term does not increase herb yield. Once established, herb species are more likely to persist under a lax grazing system with low or intermediate stocking rate.

Maintaining natural populations of predators and parasites that prey on insect pests is an important element in the design of low-input farming and sustainable systems of pest control. A long-term study is underway on the movement and population dynamics of natural populations of these beneficial organisms within the patchy mosaic of crop and semi-natural habitats (e.g. hedgerows, copses, field margins) which constitutes the agricultural landscape. Results will aid the development of strategies that conserve biodiversity in farmland and exploit natural methods of pest control, thus reducing reliance upon chemical agents.

A new molecular approach to characterising natural species diversity is described on page 43.

Roger Haggar,
Jerry Tallowin,
Institute of Grassland and Environmental Research
Wilf Powell,
Institute of Arable Crops Research

▲ **Flowering meadow: research is establishing guidelines on fertiliser limits, re-introducing lost species, management for wildlife and impact on farm income.**

Biotechnology and the general public

Public attitudes will influence the extent to which the potential of biotechnology is realised in new products and processes for industry. The Council is working to increase public awareness and widen debate on issues of biotechnology that will influence its acceptability.

Don Boulter, Scientific Consultant to the Council, is leading an analysis of public perception of genetic engineering with particular reference to the Council's programmes. Of particular interest is the way individual components of public perception of risk differ in their relative importance for different areas of research.

Perception of risk is governed not only by the hazard itself but by a reaction called "outrage". This study is analysing the relative importance of different elements of "outrage" in areas of animal, plant and microbial molecular biology. These elements include the extent to which a risk is perceived as voluntary or involuntary, diffuse or concentrated, known or unknown, and may also depend on cultural and ethical attitudes.

A major aim of the study is to understand better the basis of public perception of biotechnology. This will help the Council to present its research in ways that both provide the public with objective information on issues of legitimate concern and provide a basis for rational decision-making.

The National Museum of Science and Industry (Science Museum) has accepted a proposal from the Council to consider a consensus conference on biotechnology. The conference - a public dialogue between experts and citizens - would be the first of its kind in the UK. The approach has been used previously in Denmark and The Netherlands. The Council is considering sponsoring and providing expert evidence to the conference. The Museum would be responsible for ensuring impartiality and for publishing the findings.

The twin aims of the conference are to forward constructive public debate in Britain about biotechnology, and to test the consensus conference as a model for public debate about science and technology in this country.

Don Boulter CBE,
University of Durham
Colin Miles,
AFRC Central Office

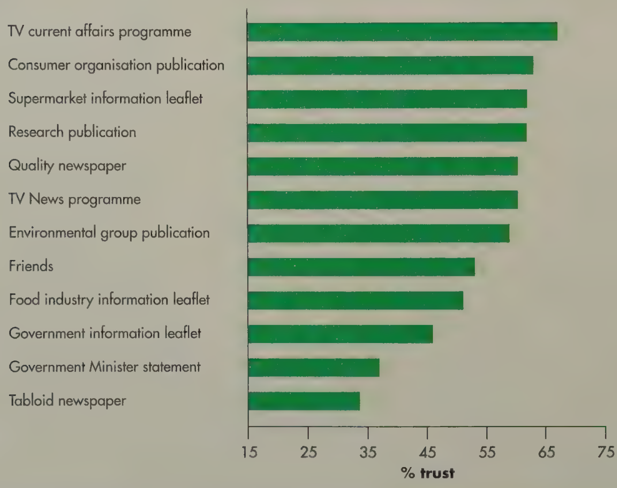
Consumer attitudes

There has been little systematic empirical research addressing public views on biotechnology but a 3 year MAFF-funded project at the Institute of Food Research is currently examining the psychological mechanisms underlying public attitudes and concerns. A series of studies, including a longitudinal national survey, has shown low awareness of the technology but a willingness to express opinions on its likely risks and benefits. Changes in views over time are being examined and initial analyses indicate reduced perceived risks and increased perceived benefits in those people re-questioned after one year.

Describing the technology in different ways (e.g. "gene technology" rather than "genetic engineering", "manipulation" or "modification") produced few differences in responses other than lower familiarity with the term "gene technology". In line with many other potential hazards, people see themselves to be at less risk from genetic engineering than are other people and believe themselves to be more knowledgeable than others. However, they feel they have little control over the technology which they see as controlled at the level of society.

People are more concerned about genetic manipulation of animals than of microorganisms and plants and state that they are more likely to trust information from consumer organisations than from the Government or from industry. Ethical concerns are of great importance in this area and exert an effect on attitudes and intention to purchase independent of the perceived personal costs and benefits of the technology. However, detailed examination of the issues underlying these ethical concerns reveals many of them to be addressable concerns such as animal welfare or human health.

Richard Shepherd,
Institute of Food Research



◀ **The extent to which different sources of information are trusted when there is no information attribution.**

Pupil attitudes

Most people acquire their knowledge of science from education at school. Pupils are a key group, therefore, in which to study likely trends in public knowledge and attitudes in the future. A collaborative study with the University of Birmingham has explored knowledge and attitudes to biotechnology and genetic engineering in two hundred GCSE students.

Despite the fact that biotechnology has a place in the National Curriculum, mainly at Key Stage 4, nearly half the students questioned were unable to give examples either of biotechnology or genetic engineering. When asked to indicate agreement or disagreement with a series of attitude statements about applications of biotechnology, pupils broadly supported genetic engineering in microbes and plants, but there was little support for applications in animals.

Roger Lock,
University of Birmingham
Colin Miles,
AFRC Central Office

STATEMENTS	I strongly agree	I agree	I'm not sure	I disagree	I strongly disagree
1. Using yeast in the production of wine is a good idea.					
2. Changing the genetic make up of farm animals should be banned by law.					
3. We should not alter the genes in tomatoes to make them ripen more slowly.					
4. Altering the genes of tomatoes so that they taste better is a good idea.					

▲ **Statements were presented to pupils to assess their attitudes to the genetic engineering of plants, animals and microbes.**

Schools liaison

The Council has expanded its programme of activities designed to provide teachers and students with resource materials that complement existing resources and provide up-to-date examples of research and its applications.

A key element in our strategy is to work collaboratively with organisations that possess expertise in teaching methods and in the requirements of teachers. We have established constructive partnerships with the National Centre for Biotechnology Education (NCBE), The Natural History Museum and the Science and Plants for Schools (SAPS) initiative. Materials produced by the Council are distributed nationally in association with the Institute of Biology, the Food and Farming Information Service and through meetings of the Association of Science Education and the British Association Youth Section. Individual institutes also provide a range of activities including, in some cases, Schools' Open Days.

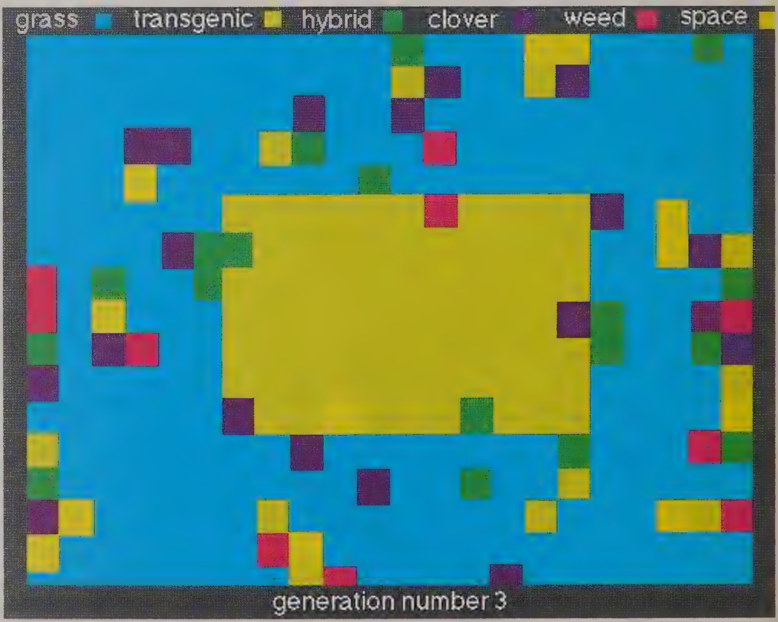
An annual schools competition is run in collaboration with NCBE; the 1992/93 competition is based on applications for liposome technology. A sixth form publication on the Nitrogen Cycle has been published in collaboration with NCBE. The Council is also supporting publication of "Practical Biotechnology" - an NCBE guide for schools and colleges, and a SAPS workshop for teachers on DNA technology. Published material in AFRC Annual Reports, brochures and AFRC News is being made available to schools in a series of "Abstracts" that target topics included in the GCSE and "A" level syllabuses.

Monica Winstanley,
AFRC Central Office

▲ **Dean Madden of the National Centre for Biotechnology Education discussing nucleotide sequencing with young visitors to the AFRC stand at the ASDA Festival of Food and Farming in Hyde Park in May 1992.**

Control and risk assessment of genetic manipulation

Public acceptability of gene transfer technologies will depend on the level of trust in the safety of such procedures and the regulations governing their use.



Computer model that predicts gene flow between grassland communities. It can predict long term changes - up to sixty years - and may be used to design and test strategies for preventing gene flow from experimental transgenic grasses. Each coloured square represents a genet of the type indicated by its colour. ▼

Council scientists are helping to design risk evaluation procedures for processes and products involving gene transfer. One example is the development of GENHAZ, a step-by-step procedure for analysing the consequences of proposed experiments. By pursuing the possible consequences of all conceivable deviations from ideal or intended behaviour, GENHAZ enables identification of where action plans are needed to avoid such consequences, and aids the development of such plans. It helps regulatory committees and researchers to quantify and sometimes eliminate potentially hazardous procedures.

Factors affecting potential routes of gene flow from transgenic crops are being analysed experimentally. This includes, for example, measurement of pollen dispersal from oilseed rape and the effects on gene flow of insect activity, flowering time and plant populations.

Microorganisms can be tracked by the introduction of "marker" genes, i.e. those coding for easily recognisable traits such as resistance to an antibiotic. The fate of organisms can be followed by screening for the marker gene. When peas on a field site were inoculated with rhizobia (root-nodulating bacteria) marked in this way, the inoculated strains were still detectable in the soil over five years later. No evidence for transfer of the marker gene to the native population has been detected. A second release of rhizobia with a different marker, to study genetic interactions with the established marked strain, is now planned.

Data on pollen and seed dispersal from grasses are being used to construct a computer model that simulates gene flow between grassland communities. About half the pollen produced by a grass falls within 15 metres of the plant, but on windy days some may travel 80 metres or more. Gene flow into grass populations depends on successful germination and establishment of seedlings. The factors governing these processes in grazed and ungrazed pasture, and the influence of physical barriers such as hedges, are being investigated and incorporated into the computer model.

Fundamental studies on natural processes of gene transfer in lactic acid bacteria are providing valuable information for the design of better contained strains for use in genetic engineering. Strains of *Lactococcus lactis* have been isolated that lack a genetic element which promotes high levels of gene transfer between one bacterial cell and another. These strains have a greatly reduced potential to transfer their genes into other bacteria in their environment, and are thus better contained genetically.

The Council has participated over the past three years in PROSAMO (Planned Release of Selected and Modified Organisms) together with ten commercial companies and the DTI's Biotechnology Unit.

Richard Flavell,
John Innes Centre
Mike Gasson,
Institute of Food Research
Glynis Giddings,
Institute of Grassland and Environmental Research
Penny Hirsch,
Institute of Arable Crops Research

Animal welfare

The Council supports research in regard of animal welfare in ten universities and colleges. This includes a new programme that commenced in 1992 under the coordination of John Webster of the University of Bristol. The work complements, and in some cases is undertaken in collaboration with, research at the Roslin, Babraham and Silsoe institutes.

The Council focus is on fundamental studies that are leading to a better understanding of basic animal behaviour and physiology as related to the welfare of farm animals. The emphasis is on basic research that will lead to long-term improvements in the factors that govern how animals perceive and respond to their environments, so that systems of husbandry, handling and transportation may be designed around the requirements of the animals (for example, see page 41).

Improving the visual environment for poultry

An animal's ability to seek novelty in its surroundings to alleviate boredom is an important aspect of welfare, particularly for highly visual animals like hens.

Investigations into how hens view and respond to different visual stimuli such as changing landscape scenery or a model of an animal are providing information about how the birds regulate what they perceive. One question being explored experimentally, for example, is whether hens will choose to view video recordings of interesting patterns or landscapes to cope with a monotonous environment.

Better understanding of visual perception in hens will enable the design of cages and housing to alleviate boredom and eliminate fear.

Richard Andrew, *University of Sussex*
Bryan Jones, *Roslin Institute*

Improved cage design for laying hens

A new cage system for laying hens has been designed that allows them to express a reasonably wide range of behaviour including some of the activities that they show in complex, natural environments. These include: roosting on a perch, laying their eggs in a secluded nest site, dust bathing with sand or earth and foraging.

The new design maintains the advantages of conventional cages: good hygiene, environmental control and small group sizes.

Mike Appleby,
University of Edinburgh
Barry Hughes,
Roslin Institute

Coping behaviour in individual pigs

Individual pigs show marked differences in their responses to external cues, their persistence at achieving goals, and their propensity to develop repetitive behaviour. It is likely that these differences in behavioural organisation have consequences for how individual pigs respond to events in their world, but it is not known what causes these differences, how stable they are across time, and how they affect ability to cope with environmental and social change.

Research is investigating these issues by examining how experience in different rearing environments affects the development and stability of behavioural organisation in pigs, and by assessing how different types of individual vary in their ability to cope with environmental and social change.

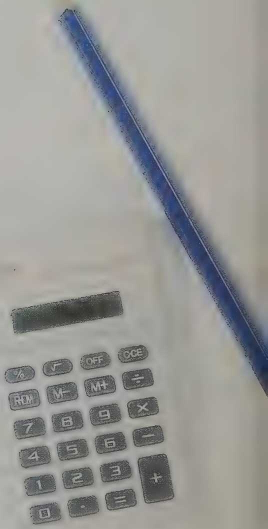
This research will shed light on how the behavioural organisation of individual pigs is affected by the husbandry and housing systems in which they are reared, and how this affects their subsequent ability to cope with stressful situations.

Michael Mendl, *Scottish Agricultural College*

◀ **Foraging is an example of a natural behaviour that can be expressed in the Edinburgh modified cage.**

Financial and other reports

Financial Statement



For the financial year ending 31 March 1993, the expenditure of the Council and Council owned institutes was *£151.6M*.

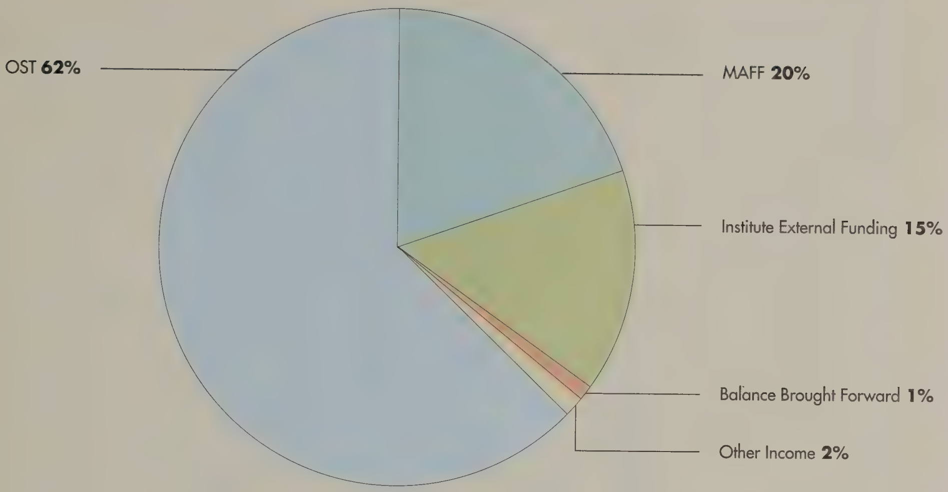
The expenditure was financed from the following sources:

Science Budget grant-in-aid from the Office of Science and Technology was *£105.4M* and commissioned research from the Ministry of Agriculture, Fisheries and Food amounted to *£35.1M*.

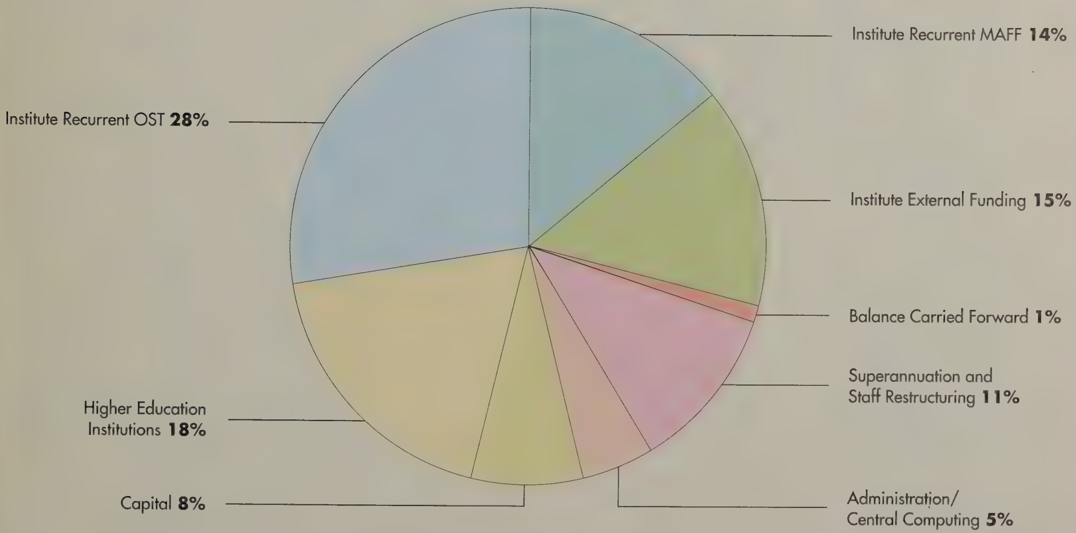
This major funding was augmented by further Council income totalling *£9.3M* being mainly contract and other income from industry and Government organisations. The balance came from miscellaneous sales.

In addition to this income received by the Council, grant-aided institutes received outside funding estimated at *£19.3M* from contracts and other agreements with industry, Government Departments, EC, Foundations and Trusts, etc. This income is included in the table on page 26.

At the year end, the Council held a balance of *£2.2M*; mainly in respect of capital commitments and commercial contracts.



Total AFRC Income for 1992/93 including External Funding of Grant-Aided Institutes (£170.8M)



Total AFRC Expenditure for 1992/93 including External Funding (£170.8M)

The full accounts are published as a House of Commons Paper available from Her Majesty's Stationery Office.

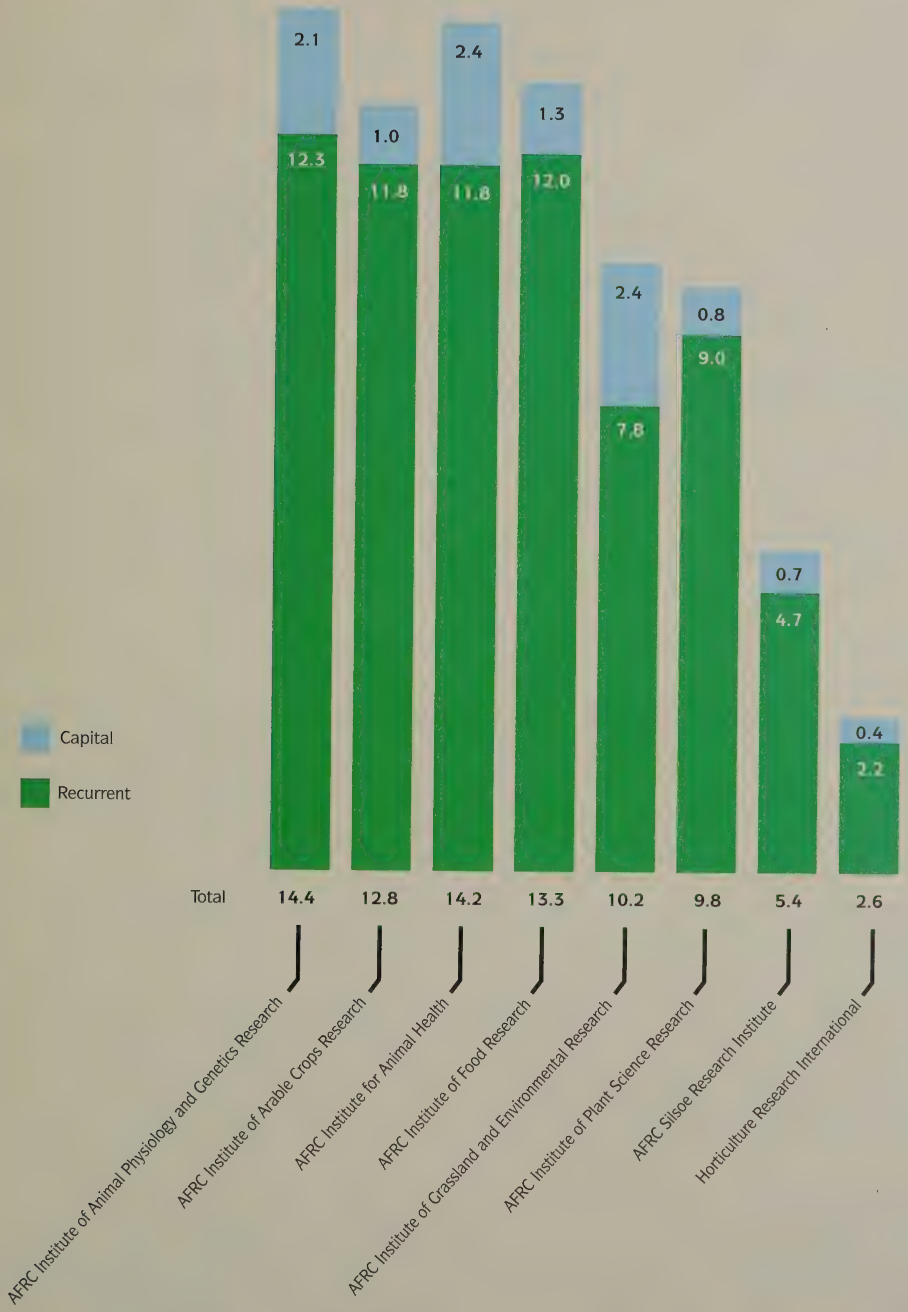
Summary of Income and Expenditure of the Council for Year Ended 31 March 1993

	1991/92		1992/93	
	£000		£000	
INCOME				
Balance brought forward	1,419		1,705	
OST Grant-in-Aid	95,567		105,439	
MAFF Commissions	34,516		35,114	
Council institutes and units	6,722		8,331	
Capital receipts/other income	3,109		1,005	
TOTAL INCOME *(including balance brought forward)*		141,333		151,594
EXPENDITURE				
Recurrent Expenditure				
Council and Grant-aided institutes	69,242		77,982	
Research Grants to HEIs	17,112		26,264	
Postgraduate Training Awards	2,263		3,648	
Administrative, Central Computing and Miscellaneous Costs	6,769		7,733	
UK Research and Higher Education European Office (Net)	-		45	
Superannuation and Staff Restructuring Costs (Net)	21,625		19,090	
TOTAL RECURRENT EXPENDITURE		117,011		134,762
Capital Expenditure				
Land and Buildings	18,681		9,150 *	
Capital Equipment	3,936		5,460	
TOTAL CAPITAL EXPENDITURE		22,617		14,610
Balance carried forward		1,705		2,222
TOTAL EXPENDITURE *(including balance carried forward)*		**141,333**		**151,594**

* Reduction from 1991/92 reflects the end of the institute restructuring programme.

Subject to Audit.

Net Cash Grants to Council and Grant-aided Institutes (£M) 1992/93



Council statistics

Human Resources

On 31 March 1993, 2,988 staff were employed on permanent appointments in the AFRC institutes and Central Office; 150 posts were vacant. Of the permanent staff, 1,403 were in the Science Group, of whom 95% were at graduate or equivalent levels. A further 735 members of staff, mainly scientists, held short-term appointments funded either by the AFRC directly (305) or by industry and other external sources (430).

Short-term posts have been increasing steadily over the last decade as the volume of short-term income has increased and now account for just on one-third of all Science Group posts. The increase in short-term appointments reflects a parallel increase in the proportion of the AFRC budget devoted to scientific staff. By March 1993, 62% of staff in AFRC institutes were in the Science Group, already in excess of the 1994/95 planning target of 61%.

HONOURS AND AWARDS

Birthday Honours

CBE: *Professor T Lewis*, Director of Research, Institute of Arable Crops Research.

BEM: *Mr G H Sherborne*, Deputy Farm Manager, Institute of Arable Crops Research.

BEM: *Mr P R Wakeman*, Deputy Workshop Supervisor, Silsoe Research Institute.

New Year Honours

CBE: *Professor W P T James*, Director, Rowett Research Institute.

OBE: Professor R M Hicks, Council Member and Chairman, Food Research Committee.

OBE: *Dr L N Payne*, Institute for Animal Health.

MBE: *Mrs A E Atchison*, former librarian, John Innes Centre.

Other Distinctions

Dr M J Adams, Institute of Arable Crops Research, received the First Class Award for Agricultural Science and Technology Achievements from the Ministry of Agriculture, The People's Republic of China.

Dr J Brownlie, Institute for Animal Health, was awarded the medal of the European Society of Veterinary Virology.

Professor G Bulfield, Roslin Institute, was elected a Fellow of the Royal Society of Edinburgh.

Dr R F Irvine, Babraham Institute, was elected a Fellow of the Royal Society.

Dr S P McGrath, Institute of Arable Crops Research, was awarded the first SCI Environment Medal.

Dr H M Schweizer, Institute of Food Research, was awarded a Professorship from the University of Friedrich Alexander at Erlangen Nürnberg, Germany.

SENIOR STAFF CHANGES

AFRC Central Office

Mr G C Clark was appointed Head of Buildings and Supplies with effect from 1 May 1992 following the retirement of *Mr B A Staples*.

Institute for Animal Health

Dr R P Kitching was appointed Head of World Reference Laboratory with effect from 1 December 1992.

Mr T W Marshall was appointed Institute Secretary with effect from 1 August 1992.

Institute of Arable Crops Research

Professor J M Anderson was appointed Chief Executive of Rothamsted International with effect from 1 January 1993.

Dr D M Glen was appointed Head of Crop and Environment Sciences with effect from 1 July 1992 following the retirement of *Dr K J Brent OBE*.

Dr R Hooley was appointed Acting Head of the Cell Biology Department with effect from 1 April 1992.

Institute of Food Research

Dr P J Aggett was appointed Head of the Nutrition, Diet and Health Department with effect from 1 April 1992 following the retirement of *Professor D A T Southgate*.

Professor P S Belton was appointed Head of Norwich Laboratory with effect from 1 July 1992.

Dr D C Clark was appointed Head of the Food Biophysics Department with effect from 1 November 1992.

Institute of Grassland and Environmental Research

Dr A B McAllan was appointed Head of the Ruminant Nutrition Department with effect from 1 September 1992.

John Innes Centre

Dr M D Gale was appointed Acting Head of the Cambridge Laboratory with effect from 1 October 1992 following the retirement of *Dr C N Law*.

Mr D J O'Nions was appointed Head of Administration with effect from 4 January 1993.

INDIVIDUAL MERIT PROMOTION

The following members of AFRS staff were awarded Individual Merit Promotion with effect from 1 July 1992:

Grade 5:

Dr K F Chater, John Innes Centre.

Dr A Surani, Babraham Institute.

Grade 6:

Dr G W Butcher, Babraham Institute.

Dr D J Flint, Hannah Research Institute.

Dr G P Hazlewood, Babraham Institute.

Dr D W Lawlor, Institute of Arable Crops Research.

Dr D J Lowe, John Innes Centre.

Professor J A Marchant, Silsoe Research Institute.

Dr P J Shaw, John Innes Centre.

Research grants and research training

Total Council expenditure rose from ***£19.4M*** (1991/92) to ***£29.9M.***

- expenditure on research grants schemes increased to ***£25.9M***
- research studentships totalled ***290*** (average value of stipends ***£6.2K***)
- a further ***7*** Postdoctoral Fellowships were awarded

The Council continues to administer two charitable funds that promote international exchange of scientists. The Wain Fund provides grants for members of staff of UK universities to work overseas, and Fellowships for study abroad by academic staff of universities, including those who have recently completed postgraduate training and expect to enter a research career. Income from the fund for 1992/93 was ***£34,368***.
The Underwood Fund provides grants for distinguished overseas scientists to visit the UK and undertake research. Income from the fund for 1992/93 was ***£56,390***.

Expenditure on research grants and research training

	1991/92 (£M)	*1992/93* (£M)
Responsive Mode	9.88	13.73
Linked	3.00	5.07
Cooperative	0.22	0.21
Centre for Genome Research	1.23	2.25
Coordinated Programmes	2.79	5.00
Research Training/Fellowships	2.26	3.65
Total	**19.38**	**29.91**

Coordinated Programmes

Council expenditure in each Programme when fully operational

Programme	**Starting Date**	**Duration (Years)**	**Total Expenditure (£M)**
Agriculture & Environment*	1990	3	1.8
Bovine Spongiform Encephalopathy	1990	4	9.0
Clean Technology*	1990	4	0.8
Biochemistry of Metabolic Regulation in Plants I*	1991	3	0.5
Pollutant Transport in Soils and Rocks*	1991	3	0.6
Stem Cell Molecular Biology	1991	3	7.5
Transition Metals in Biology and their Coordination Chemistry*	1991	3	0.3
Biochemistry of Metabolic Regulation in Plants II*	1992	4	1.2
Biological Adaptation to Global Environmental Change	1992	4	8.0
Plant Molecular Biology II	1992	4	8.0
Intracellular Signalling	1992	4	9.0
Plant & Animal Genome Analysis	1993	3	2.1

*Jointly with other Research Councils

Coordinated programmes bring together research in institutes and universities.

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INSTITUTES

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Professor R B Heap FRS

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Director:
Professor F J Bourne

Institute of Arable Crops Research (IACR)
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(From March 1994,
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Dyfed SY23 3EB
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Dr C J Pollock)

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Norwich Research Park
Colney Lane
Norwich NR4 7UH
Telephone: (0603) 52571
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Roslin Institute *
Roslin
Midlothian EH25 9PS
Telephone: (031) 440 2726
Director:
Professor G Bulfield FRSE

Silsoe Research Institute (SRI)
Wrest Park
Silsoe
Bedford MK45 4HS
Telephone: (0525) 860000
Director:
Professor B J Legg

* *Previously part of Institute of Animal Physiology & Genetics Research*

** *Including the Institute of Plant Science Research, IPSR*

SCOTTISH AGRICULTURAL RESEARCH INSTITUTES

These institutes, funded by the Scottish Office Agriculture and Fisheries Department, are also part of the Agricultural and Food Research Service. They are not reported on in detail here.

Hannah Research Institute (HRI)
Ayr KA6 5HL
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Director:
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Aberdeen AB9 2QJ
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Scottish Crop Research Institute (SCRI)
Invergowrie
Dundee DD2 5DA
Telephone: (0382) 562731
Director:
Professor J R Hillman

ACRONYMS

ADAS Agricultural Development and Advisory Service

AFRC Agricultural and Food Research Council

AFRS Agricultural and Food Research Service

BBSRC Biotechnology and Biological Sciences Research Council

BLAD Bovine Leucocyte Adhesion Deficiency

BS Bundle sheath

BSE Bovine Spongiform Encephalopathy

BTG British Technology Group

CMV Cucumber mosaic virus

CNRS Centre National de la Recherche Scientifique

CWIS Collaboration With Industry Scheme

DANI Department of Agriculture for Northern Ireland

DLO Dienst Landbouwkundig Onderzoek

DNA Deoxyribonucleic acid

DTI Department of Trade and Industry

EC European Community

ECU European Currency Unit

EEIG European Economic Interest Group

EFTA European Free Trade Association

ESF European Science Foundation

ESRC Economic and Social Research Council

ETSU Energy Technology Support Unit

FMD Foot-and-mouth disease

FMDV Foot-and-mouth disease virus

FRAP Fluorescence recovery after photobleaching

FTIR Fourier Transform Infrared Spectroscopy

GABA Gamma-amino butyric acid

HEI Higher Education Institution

INRA Institut National de la Recherche Agronomique

ISAAA International Service for Acquisition of Agri-biotech Applications

ISIS International Scientific Interchange Scheme

LDL Low density lipoprotein

Mab Monoclonal antibody

MAFF Ministry of Agriculture, Fisheries and Food

MRC Medical Research Council

mRNA Messenger ribonucleic acid

NCBE National Centre for Biotechnology Education

NERC Natural Environment Research Council

NRI Natural Resources Institute

OASIS Online agricultural sciences information system

ODA Overseas Development Administration

OECD Organisation for Economic Cooperation and Development

OPSS Office of Public Service and Science

OST Office of Science and Technology

PCR Polymerase chain reaction

PSD Pesticides Safety Division

QTL Quantitative trait loci

RCNMV Red clover necrotic mosaic virus

RNA Ribonucleic acid

SAPS Science and Plants for Schools

SERC Science and Engineering Research Council

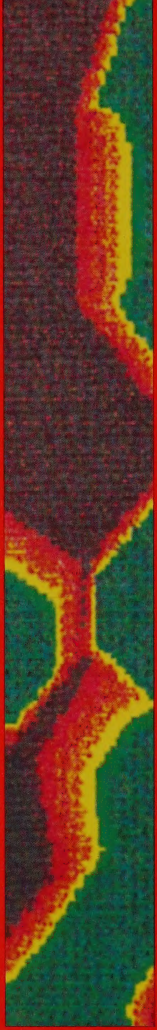
SOAFD Scottish Office Agriculture and Fisheries Department

SUNDIAL Simulation of Nitrogen Dynamics in Arable Land

Designed and Produced by
Studio 108, Corsham, Wiltshire

Printed in England

◀ a plant virus manipulated to carry a fragment of foot-and-mouth disease virus - a potentially exciting approach to vaccine technology for the pharmaceutical industry *(page 15)*.



◀ geographical distribution of crops under different climate scenarios - a tool for designing policies for land use to meet the challenges and opportunities of environmental change *(page 32)*.

◀ predicted gene flow between grassland communities - part of a programme on control methods and risk evaluation, crucial to public debate about the acceptability of biotechnology *(page 54)*.

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